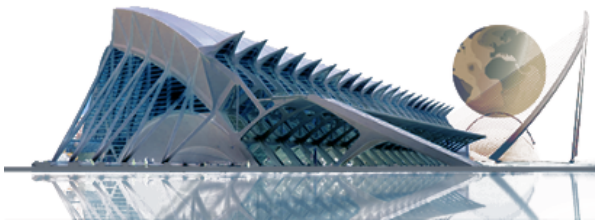


ISCRAM 2019

16 TH INTERNATIONAL CONFERENCE ON INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

CONFERENCE PROCEEDINGS

16th International Conference on Information Systems for Crisis Response and Management

Valencia (Spain), May 19-22

Editors

Zeno Franco

José J. González

José H. Canós

ISBN 978-84-09-10498-7

ISSN 2411-3387

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

anys

ISCRAM

Index

ISCRAM 2019: Towards individual-centric emergency management systems ... xiii

Scientific Committee xv

Organization Committee xvi

Sponsors xvii

Invited Talks xviii

Professional day xxii

Workshops xxiii

Track Chairs xxv

Reviewers xxviii

ISCRAM 2019 Best Paper Awards Nominees xxx

Tracks

Track 1. Analytical Modeling and Simulation..... 1

CoRe papers

Reliability of expert estimates of cascading failures in Critical Infrastructure; Ahmed Abdeltawab Abdelgawad, Jose J. Gonzalez; Centre for Integrated Emergency Management (CIEM), University of Agder, Norway (ID 113) 2

Simulation Analysis of Fire Hydrant Usability Levels after Large Earthquake; Toshihiro Osaragi, Noriaki Hirokawa; Tokyo Institute of Technology (ID 122) 22

Simulation Platform for Unmanned Aerial Systems in Emergency Ad Hoc Networks; Patrick Lieser, Julian Zobel, Björn Richerzhagen, Ralf Steinmetz; Technical University Darmstadt, Germany (ID 137) 36

Understanding the Main Themes Towards a Visual Analytics Based Model for Crisis Management Decision-Making; Flavio Dusse[1], Renato Novais[2], Manoel Mendonça[1] ; [1]UFBA, Brazil; [2]IFBA, Brazil (ID 139).. 51

The Dynamics of Cyber Resilience Management; Juan Francisco Carías[1], Leire Labaka[1], Jose Maria Sarriegi[1], Andrea Tapia[2], Josune Hernantes[1] ; [1]University of Navarra, TECNUN, Spain; [2]Pennsylvania State University, USA (ID 140) 64

ESCAPE: Exploring by Simulation Cities Awareness on Population Evacuation; Eric Daudé[1], Kevin Chapuis[2], Clément Caron[1], Alexis Drogoul[2], Benoit Gaudou[2,5], Sebastien Rey-Coyrehourq[1], Arnaud Saval[3], Patrick Taillandier[4], Pierrick Tranouez[3], Jean-Daniel Zucker[2] ; [1]Université de Normandie, UMR 6266, IDEES, Rouen, France; [2]Sorbonne University, IRD, UMMISCO; [3]University of Rouen Normandie, EA LITIS; [4]University of Toulouse, INRA, MIAT; [5]University of Toulouse Capitole, IRIT (ID 145) 76

WiPe papers

Assessing Flood Recovery of Small Businesses using Agent-Based Modelling and Simulation; Meshal Alharbi[1], Graham Coates[2]; [1]Durham University, United Kingdom; [2]Newcastle University, United Kingdom (ID 184) 94

Location-allocation model for earthquake shelter solved using MPSO algorithm; Xiujuan Zhao[1], Jianguo Chen[1], Peng Du[2], Wei Xu[3], Ran Liu[2], Hongyong Yuan[1] ; [1]Tsinghua University, China, People's Republic of; [2]Beijing Global Safety Technology Co., Ltd, China, People's Republic of; [3]Beijng Normal University, China, People's Republic of (ID 191) 105

Improving Emergency Response through Business Process, Case Management, and Decision Models; Marco Polo Ruiz Herrera, Juan Sánchez Díaz; Universitat Politècnica de València, Spain (ID 210) 116

Simulation of Crowd Response During Emergency Considering People's Rational and Irrational Thinking; Anying Chen, Guofeng Su, Manchun Liang; Tsinghua University, People's Republic of China (ID 217) 126

A Preliminary Optimisation-based Approach to Coordinate the Response of Ambulances in Mass Casualty Incidents; Haya Aldossary, Graham Coates; Newcastle University, United Kingdom (ID 218) ... 139

A New Data-Driven Approach to Measuring Hurricane Risk; Duygu Pamukçu[1], Christopher William Zobel[1], Andrew Arnette[2]; [1]Virginia Tech, United States of America; [2]University of Wyoming, United States of America (ID 240) 151

Track 2. Command and Control Studies 158

CoRe papers

Cause and Effect: A Qualitative Analysis of Obstacles to Information Sharing During a Regional Disaster Exercise; Abbas Ganji, Tom Wilson, Sonia Saveli, Dharma Dailey, Mark Haselkorn; University of Washington, United States of America (ID 103) 159

Supporting Inter-Organizational Learning – A Review of Post-Excercise Knowledge Sharing; Johan Nordström, Björn Johan Erik Johansson; Swedish Defence Research Agency (ID 116) 173

Opportunistic Affiliation in Spontaneous Volunteer Management; Daniel Auferbauer[1], Roman Ganhör[2], Hilda Tellioğlu[2]; [1]AIT Austrian Institute of Technology; [2]TU Wien (ID 126) 186

WiPe papers

Analysis of Common Operational Picture and Situational Awareness during Multiple Emergency Response Scenarios; Kristine Steen-Tveit, Jaziar Radianti; University of Agder, Norway (ID 196) 199

Who Learns from Crisis Management Exercises: An Explorative Study; Mari Olsén, Niklas Hallberg, Kristoffer Darin Mattsson; Swedish Defence Research Agency, Sweden (ID 202) 209

Evaluating the observation protocol of the Team Resilience Assessment Method for Simulation (TRAMS); Amanda Jaber[1], Björn Johan Erik Johansson[1], Linnea Bergsten[1], Joeri Laere van[2], Peter Berggren[1]; [1]Linköping University, Sweden; [2]Skövde University, Sweden (ID 206) 218

Design to Fit – Morphological Analysis as a Tool for Exercise Design; Pär Hans Tuve Eriksson, Niklas Hallberg; FOI, Sweden (ID 219) 230

Do's and Don'ts in Inter-Organizational Crisis Management Exercises; Kristoffer Karl Darin-Mattsson, Niklas Hallberg; Swedish Defence Research Agency (FOI), Sweden (ID 223) 242

Testing the implementation of a flying localization system into emergency response using a tabletop exercise; Sebastian Schmitz, Konrad Barth, Tim Brüstle, Tobias Gleibs, Ompe Aimé Mudimu; TH Köln – University of Applied Sciences (ID 230) 252

Track 3. Ethical, Legal and Social Issues 262

WiPe papers

Efficiently allocating safety tips after an earthquake – lessons learned from the smartphone application LastQuake; Laure Fallou[1], Laura Petersen[2], Rémy Bossu[1,3], Frédéric Roussel[1] ; [1]Euro-Mediterranean Seismological Centre (EMSC), France; [2]Centre National de Recherche Scientifique (CNRS), France; [3]CEA, DAM, DIF, F-91297 Arpajon, France (ID 209) 263

What can we learn from a crisis management exercise? Trusting social media in a french firefighters' department; Florent Castagnino; Telecom ParisTech, France (ID 233) 276

On Liquid Ground: Contesting the facts around Shouguang Flood on Weibo; Lixiong Chen, Monika Buscher, Yang Hu; Lancaster University, United Kingdom (ID 245) 288

Managing Risk Across Borders: ethical implications of engaging information technology for transboundary disaster collaboration; Katrina Petersen; Trilateral Research Ltd., United Kingdom (ID 248) 298

Track 4. Logistics and Supply-Chain Management in Crisis Response..... 306

WiPe paper

Towards Social Media Decision Support for Joined EMS and Crisis Logistics; Kathrin Eismann[1], Melanie Reuter-Oppermann[2], Kai Fischbach[1]; [1]University of Bamberg, Germany; [2]Karlsruhe Institute of Technology, Germany (ID 201) 307

Track 5. Intelligent and Semantic Web Systems..... 317

WiPe papers

Sharing Gut Feelings to Support Collaborative Decision Making; Frâncila Weidt Neiva[1], Marcos Roberto da Silva Borges[1]; [1]Universidade Federal do Rio de Janeiro (UFRJ), Brasil (ID 155) 318

How to build an innovative C2 system supporting individual-centric emergency needs?; Guillaume Lambert[1], Bruno Fontaine[2], Michel Monneret[1], Mourad Madani[1]; [1]French Ministry of Interior, France; [2]ToMCo, digital strategy advisor (ID 171) 327

Vigi Flood: a serious game for understanding the challenges of crisis communication; Carole Adam[1], Eric Andonoff[2]; [1]University Grenoble-Alpes, France; [2]University Toulouse-Capitole, France (ID 181) 338

Multi-agent geospatial simulation of human interactions and behaviour in bushfires; Mancheva Lyuba, Adam Carole, Dugdale Julie; Univ. Grenoble Alpes, LIG, F-38000 Grenoble, France (ID 186) 352

Data Acquisition for ad-hoc Evacuation Simulations of Public Buildings; Ingo J. Timm, Bernhard Hess, Fabian Lorig; Trier University, Germany (ID 215) 367

Communication in Emergency Management through Data Integration and Trust: an introduction to the CEM-DIT system; Fiona Jennet McNeill[1], Diana Bental[1], Jeremy Bryan[2], Paolo Missier[3], Jannetta S. Steyn[3], Tom Kumar[3]; [1]Heriot-Watt University, Scotland; [2]Coventry University, United Kingdom; [3]Newcastle University, United Kingdom (ID 227) 376

Real-time Emergency Response through Performant IoT Architectures; Claudio Arbib[1], Davide Arcelli[1], Julie Dugdale[2], Mahyar Tourchi Moghaddam[1], Henry Muccini[1]; [1]University of L'Aquila, Italy; [2]University of Grenoble (ID 252) 388

Track 6. Geospatial Technologies and Geographic Information Science for Crisis Management 402

CoRe paper
Exploring multiplexing tools for co-visualization in crisis unitsd; Christelle Pierkot[1], Sidonie Christophe[2], Jean François Girres[1] ; [1]Univ. Paul-Valéry Montpellier 3, IRD, UMR GRED 220, F34000 Montpellier, France; [2]Univ. Paris-Est, LASTIG GEOVIS, IGN, ENSG, F-94160 Saint-Mande, France (ID 131) 403

WiPe papers
Semantic Understanding of Human Mobility Lifestyle to support Crisis Management; Humasak Tommy Argo Simanjuntak, Fabio Ciravegna; The University of Sheffield, United Kingdom (ID 134) 421

Sorting the good from the bad smartphone application to alert residents in case of disasters - Experiments in France; Esteban Bopp[1], Johnny Douvinet[1], Damien Serre[2] ; [1]UMR ESPACE 7300 CNRS, Département de Géographie, Université d'Avignon; [2]Ecosystèmes Insulaires Océaniens, UMR 241, Université de la Polynésie Française (ID 141) 435

Identifying potential landslide location using Unmanned Aerial Vehicles (UAVs); Jorge Vargas-Florez[1], Grovher Palomino[2], Andres Flores[1], Gloria Valdivia[2], Carlos Saito[1], Daniel Arteaga[2], Mario Balcazar[1], Miguel Fernandez[1], José Oliden[2], Daniel Díaz[2] ; [1]Pontifical Catholic University of Peru, Peru; [2]National University of Engineering (ID 148) 450

Evaluating the effects of consecutive hurricane hits on evacuation patterns in Dominica; Martin Hilljegerdes[1], Ellen-Wien Augustijn-Beckers[2] ; [1]GIScience Research Group, Institute of Geography, Heidelberg University, Germany; [2]Department of Geo-Information Processing, Faculty of Geo-Information Science and Earth Observation,University of Twente, The Netherlands (ID 220) 462

Instagrammers report about the deadly wildfires of East Attica, 2018, Greece: An introductory analytic assessment for disaster management purposes; Stathis G. Arapostathis; Harokopio Univesrsity, Greece (ID 244) 473

Track 7. Planning, Foresight and Risk Analysis 482

CoRe papers
Challenges in Community Resilience Planning and Opportunities with Simulation Modeling; Abbas Ganji, Negin Alimohammadi, Scott Miles; University of Washington, USA (ID 133) 483

Combining a social science approach and GIS-based simulation to analyse evacuation in natural disasters: A case study in the Chilean community of Talcahuano; Susanne Kubisch[1], Johanna Stötzer[1], Sina Keller[1], María Bull[2], Andreas Braun[1]; [1]Karlsruhe Institute of Technology, Germany; [2]Universidad Católica de la Santísima Concepción, Chile (ID 138) 497

Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios; Sebastian Lindner, Stefan Sackmann, Hans Betke; Martin Luther University Halle-Wittenberg, Germany (ID 146)..... 516

WiPe papers
Applying Generic AcciMap to a DDOS Attack on a Western-European Telecom Operator; Hans C.A. Wienen[1], Faiza A. Bukhsh[1], Eelco Vriezekolk[2], Roel J. Wieringa[1]; [1]University of Twente, Netherlands, The; [2]Agentschap Telecom, The Netherlands *(ID 189)* 528

Medical Resources assignments for Disaster Medical relief Forces Using an Injury-Driven Ontology Model; Min Zhu[1,2], Ruxue Chen[1], Shaobo Zhong[3], Quanyi Huang[2], Jing Ouyang[1], Guang Tian[1]; [1]6th Medical Center of General Hospital of PLA, China; [2]Tsinghua University, China; Beijing Research Center of Urban Systems Engineering, Beijing, China (ID 190) 536

A Delphi approach for the establishment of the fundamental principles of an Organizational Security System in Public Administration; Victor Amadeo Bañuls Silvera[1], Rafael Cantueso Burguillos[2], Fernando Tejedor Panchón[3], Miguel ignacio Ramírez de la Huerga[3], Murray Turoff[4], [1]Universidad Pablo de Olavide,

Spain; [2]Junta de Andalucía, Spain; [3]MSIG Smart Management, Spain; [4]New Jersey Institute of Technology, USA (ID 204) 549

Towards an organization certified in emergency plans management; Ana Gabriela Núñez Avila, Mª Carmen Penadés Gramage; Universitat Politècnica de València, Spain (ID 207) 559

Towards a Capability Model for Emergency Training Improvement; Patricia Quiroz-Palma[1,2], Ma Carmen Penadés[1], Ana-Gabriela Núñez[1]; [1]Universitat Politècnica de Valencia, Spain; [2]Universidad Laica Eloy Alfaro de Manabi, Manta-Ecuador (ID 211) 566

Towards an Automatic Assistance in Crisis Resolution with Process Mining; Hoang Nam Ho[2], Mourad Rabah[1], Ronan Champagnat[1], Frédéric Bretrand[1]; [1]Université de La Rochelle / L3i, France; [2]Kereon intelligence, France (ID 213) 574

From Hindsight to Foresight: using collaborative methodologies to tackle the wicked problems and improve the Emergency System; Marian Zulean[1], Gabriela Prelipcean[2], Florin Druga[3]; [1]University of Bucharest, ICUB, Romania; [2]University "Stefan cel Mare" Suceava; [3]University of Bucharest, Romania (ID 229) 586

Information collection using process visualisation in the risk management concept for emergency response; Christoph Amelunxen, Janina Isabella Sander; Paderborn University, Germany (ID 243) 593

The Design of a Mobile Application for Crowdsourcing in Disaster Risk Reduction; Quynh Nhu Nguyen, Claudio Rossi, Antonella Frisiello, Links Foundation, Italy (ID 256) 607

Track 8. Social Media in Crisis and Conflicts 619

CoRe papers

Social Media Use in Emergencies of Citizens in the United Kingdom; Thomas Spielhofer[2], Anna Sophie Hahne[2], Christian Reuter[1], Marc-André Kaufhold[1], Stefka Schmid[1] ; [1]Technische Universität Darmstadt, Science and Technology for Peace and Security (PEASEC), Germany; [2]The Tavistock Institute of Human Relations (TIHR) (ID 104) 620

Identifying Disaster Damage Images Using a Domain Adaptation Approach; Xukun Li[1], Doina Caragea[1], Cornelia Caragea[2], Muhammad Imran[3], Ferda Ofli[3] ; [1]Department of Computer Science, Kansas State University, United States of America; [2]Department of Computer Science, University of Illinois at Chicago, United States of America; [3]Qatar Computing Research Institute, Hamad Bin Khalifa University, Qatar (ID 109) 633

Integrating Social Media into a Pan-European Flood Awareness System: A Multilingual Approach; Valerio Lorini[1,2], Carlos Castillo[2], Francesco Dottori[1], Milan Kalas[3], Domenico Nappo[1], Peter Salamon[1]; [1]European Commission, Joint Research Centre (JRC), Ispra, Italy; [2]Universitat Pompeu Fabra, Barcelona, Spain; [3]KAJO, Slovakia (ID 111) 646

Rumour Detection on Social Media for Crisis Management; Sooji Han, Fabio Ciravegna; The University of Sheffield, United Kingdom (ID 118) 660

Information Uses and Gratifications Related to Crisis: Student Perceptions since the Egyptian Uprising; Steven Sheetz[1], Andrea Kavanaugh[1], Edward Fox[1], Riham Hassan[2], Seungwon Yang[3], Mohamed Magdy[4], Shoemaker Donald[1] ; [1]Virginia Tech, United States of America; [2]Microsoft; [3]Louisiana State University; [4]Arab Academy of Science and Technology (ID 120) 674

TREC Incident Streams: Finding Actionable Information on Social Media; Richard McCreadie[1], Cody Buntain[2], Ian Soboroff[3] ; [1]University of Glasgow, United Kingdom; [2]New York University, USA; [3]National Institute of Standards and Technology, USA (ID 127) 691

Detecting Disaster Recovery Activities via Social Media Communication Topics; Yuya Shibuya, Hideyuki Tanaka; The University of Tokyo, Japan (ID 150) 706

CrisisDPS: Crisis Data Processing Services; Firoj Alam, Ferda Ofli, Muhammad Imran; Qatar Computing Research Institute, Qatar (ID 152) 719

Integrating Social Media in Emergency Dispatch via Distributed Sensemaking; Rob Grace[1], Shane Halse[1], Jess Kropczynski[2], Andrea Tapia[1]; [1]Pennsylvania State University, United States of America; [2]University of Cincinnati, United States of America (ID 159) 734

WiPe papers

Counter Narratives in Social Media: An Empirical Study on Combat and Prevention of Terrorism; Amanda Langer[1], Marc-André Kaufhold[1,2], Elena Maria Runft[1], Christian Reuter[2], Margarita Grinko[1], Volkmar Pipek[1] ;[1]University of Siegen, Institute for Information Systems, Germany; [2]Technische Universität Darmstadt, Science and Technology for Peace and Security (PEASEC), Germany (ID 119) 746

Understanding patterns and mood changes through tweets about disasters; Liuqing Li, Edward A. Fox; Virginia Tech, United States of America (ID 121) 756

Filtering images extracted from social media in the response phase of emergency events; Sara Barozzi[1], Jose Luis Fernandez Marquez[2], Amudha Ravi Shankar[2], Barbara Pernici[1] ; [1]Politecnico di Milano; [2]University of Geneva (ID 142) 768

Simulating real-time Twitter data from historical datasets; Shane Errol Halse[1], Rob Grace[1], Jess Kropczynski[2], Andrea Tapia[1] ; [1]PSU, United States of America; [2]University of Cincinnati (ID 160)..... 780

Sympathy Detection in Disaster Twitter Data; Yingjie Li[1], Seoyeon Park[1], Cornelia Caragea[1], Doina Caragea[2], Andrea Tapia[3]; [1]University of Illinois at Chicago, United States of America; [2]Kansas State University, United States of America; [3]Pennsylvania State University, United States of America (ID 161).... 788

Requirements for Software to Support the use of Social Media in Emergency Management: A Delphi Study; Starr Roxanne Hiltz[1], Amanda Hughes[2], Muhammad Imran[3], Linda Plotnick[1], Robert Power[4], Murray Turoff[1] ; [1]NJIT, United States of America; [2]Brigham Young U.; [3]Qatar Computing Research Inst.; [4]Commonwealth Scientific and Industrial Research Organisation, Australia (ID 169) 799

Robust filtering of crisis-related tweets; Jens Kersten[1], Anna Kruspe[1], Matti Wiegmann[2], Friederike Klan[1] ; [1]German Aerospace Center (DLR), Germany; [2]Bauhaus-Universität Weimar (ID 173) 814

Detecting event-related tweets by example using few-shot models; Anna Kruspe, Jens Kersten, Friederike Klan; German Aerospace Center (DLR), Germany (ID 175) 825

Facebook Disaster Maps: Aggregate Insights for Crisis Response & Recovery; Paige Maas, Shankar Iyer, Andreas Gros, Wonhee Park, Laura McGorman, Chaya Nayak, P. Alex Dow; Facebook, United States of America (ID 176) 836

#CampFireMissing: An Analysis of Tweets About Missing and Found People From California Wildfires; Humaira Waqas, Muhammad Imran; Qatar Computing Research Institute, Qatar (ID 179) 848

Comparison of Social Media in English and Russian During Emergencies and Mass Convergence Events; Fedor Vitiugin[1], Carlos Castillo[2]; [1]Independent; [2]Universitat Pompeu Fabra (ID 180) 857

When Official Systems Overload: A Framework for Finding Social Media Calls for Help during Evacuations; Steve Peterson[1], Keri Stephens[2], Hemant Purohit[3], Amanda Hughes[4] ; [1]National Institutes of Health, United States of America; [2]The University of Texas at Austin; [3]George Mason University; [4]Brigham Young University (ID 192) 867

Enhancing the usability of a disaster app: exploring the perspective of the public as users; Marion Lara Tan[1], Raj Prasanna[1], Kristin Stock[1], Emma Hudson-Doyle[1], Graham Leonard[2], David Johnston[1]; [1]Massey University, New Zealand; [2]GNS Science, New Zealand (ID 212) 876

Predicting Hurricane Damage Using Social Media Posts Coupled with Physical and Socio-Economic Variables; Guoqin Ma, Chittayong Surakitbanharn; Stanford University, United States of America (ID 221) 887

Towards Automated Individual Communication for Coordination of Spontaneous Volunteers; Sophie Gerstmann, Hans Betke, Stefan Sackmann; Martin-Luther University Halle-Wittenberg, Germany (ID 231). 897

Evaluation of Digital Volunteers using a Design Approach: Motivations and Contributions in Disaster Response; Gabriela C Barrera, Maria C Yang; MIT, Cambridge, MA, United States of America (ID 236) 906

Refining a Coding Scheme to Identify Actionable Information on Social Media; Jess Kropczynski[1], Rob Grace[2], Shane Halse[2], Doina Caragea[3], Cornelia Caragea[4], Andrea Tapia[2] ; [1]Uiniversity of Cincinnati, United States of America; [2]The Pennsylvania State University; [3]Kansas State University; [4]University of Illinois at Chicago (ID 247) 916

Real-time Adaptive Crawler for Tracking Unfolding Events on Twitter; Asmelash Teka Hadgu[1], Sallam Abualhaija[2], Claudia Niederée[1] ; [1]L3S Research Center, Leibniz universität Hannover, Germany; [2]Interdisciplinary Centre for Security, Reliability and Trust (ID 251) 923

Track 9. Universal Design of ICT in Emergency Management..... 932

WiPe papers

Life-Area Broadcasting System (LABS) for Usual and Emergency Cases by Using Easy Contents Management System and New Speaker Devices; Jun Sasaki[1], Taeko Maejima[1], Shuang Li[1], Yusuke Sato[2], Minoru Hiyama[3]; [1]Iwate Preefctural University, Japan; [2]Sato Watch Ltc.; [3]Holonic Systems Ltc. (ID 177)... 933

Understanding Situational Disabilities and Situational Awareness in Disasters; Terje Gjøsæter[1], Jaziar Radianti[2], Weiqin Chen[1] ; [1]Oslo Metropolitan University; [2]Centre for Integrated Emergency Management, University of Agder (ID 188) 940

Track 10. Knowledge, Semantics and AI for Risk and Crisis Management..... 950

CoRe papers

An Automatic Approach to Qualitative Risk Assessment in Metropolitan Areas; Denis Barcaroli[1], Alex Coletti[2], Antonio De Nicola[1], Antonio Di Pietro[1], Luigi La Porta[1], Maurizio Pollino[1], Vittorio Rosato[1], Giordano Vicoli[1], Maria Luisa Villani[1], Enrico Zavagnini[1]; [1]ENEA, Italy; [2]Booz Hallen Hamilton, United States (ID 147) 951

SEMIoTICS: Semantic Model-Driven Development for IoT Interoperability of Emergency Services; Joao Moreira, Luis Ferreira Pires, Marten Sinderen; U.Twente, The Netherlands (ID 149) 961

WiPe papers

Generating Crisis Situation by Using Ontology and Fuzzy Theory; Sammy Abdelghani Teffali, Nada Matta, Eric Chatelet; University of technology of Troyes, France (ID 108) 974

Situation Representation and Awareness for Rescue Operations; Samer CHEHADE[1,2], Nada MATTA[1], Jean-Baptiste POTHIN[2], Remi COGRANNE[1]; [1]University of Technology of Troyes, France; [2]DataHertz, France (ID 114) 980

Video Summarization And Video Highlight Selection Tools To Facilitate Fire Incident Management; Florian Vandecasteele, Krishna Kumar, Kenzo Milleville, Steven Verstockt; Ghent University - IDLAB, Belgium (ID 115) 992

Casualty Information Extraction and Analysis from News; Basanta Chaulagain, Aman Shakya, Bhuwan Bhatt, Dip Kiran Pradhan Newar, Sanjeeb; Prasad Panday, Rom Kant Pandey; Dept. of Electronics and Computer Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal (ID 187) 1002

A Unified Approach Integrating Human Shared Mental Models with Intelligent Autonomous Team Formation for Crisis Management; Prithviraj Dasgupta[1], Deepak Khazanchi[1,2] ; [1]University of Nebraska Omaha, United States of America; [2]Center for Integrated Emergency management (CIEM), University of Agder, Norway (ID 193) 1012

A Modular Ontology for Semantically Enhanced Interoperability in Operational Disaster Response; Linda Elmhadhbi, Mohamed-Hedi Karray, Bernard Archimède; University of Toulouse, France (ID 226) 1021

Track 11. Community Engagement & Healthcare Systems..... 1030

CoRe papers

Taxonomy of Community Interaction in Crises and Disasters; Daniel Auferbauer[1], Christoph Ruggenthaler[1], Gerald Czech[2], Ivan Gojmerac[1] ; [1]AIT Austrian Institute of Technology; [2]Austrian Red Cross (ID 130) 1031

Identifying functions for smartphone based applications in volunteer emergency response; Elina Ramsell, Tobias Andersson Granberg, Sofie Pilemalm; Linköping University, Sweden (ID 136) 1044

WiPe papers

Trends in Humanitarian Health Information during 2010 Haiti Earthquake: Motivation for Curating Domain Knowledge Base; Jennifer Lisa Chan[1], Gabriel Nam[2], Allison G. Marshall[3], Hemant Purohit[4] ; [1]Northwestern University, United States of America; [2]University of Pennsylvania,United States of America; [3]Temple University, United States of America; [4]George Mason University, United States of America (ID 195) 1057

Community resilience towards disruptions in the payment system; Peter Berggren[1], Molly Lundberg[1], Joeri van Laere[2], Björn J E Johansson[1]; [1]Linköping University, Sweden; [2]Skövde University (ID 203) 1070

Visualizing Early Warning Signs of Behavioral Crisis in Military Veterans: Empowering Peer Decision Support; Olawunmi George[1], Rizwana Rizia[1], MD Fitrat Hossain[1], Nadiyah Johnson[1], Carla Echeveste[2], Jose Lizarraga Mazaba[2], Katinka Hooyer[2], Zeno Franco[2], Mark Flower[3], Sheikh Iqbal Ahamed[1], Praveen Madiraju[1], Lisa Rein[2]; [1]Marquette University; [2]Medical College of Wisconsin; [3]Dryhootch of America (ID 214) 1077

Designing Disaster Information Management Systems 2.0: Connecting communities and responders; Kenny Meesters, Vittorio Nespeca, Tina Comes; Delft University of Technology, The Netherlands (ID 216) 1089

The reciprocity of data integration in disaster risk analysis; David Paulus, Kenny Meesters, Gerdien de Vries, Bartel Van de Walle; TU Delft, The Netherlands (ID 222) 1103

Review-based taxonomy of post-impact volunteerism types to improve citizen integration into crisis response; Robin Batard[1,2], Caroline Rizza[1], Aurélie Montarnal[2], Frédérick Bénaben[2], Christophe Prieur[1];[1]Telecom ParisTech; [2]IMT Mines Albi (ID 234) 1114

Track 12. Tool Talks..... 1125

CoRe papers

Management of Sensor Data with Open Standards; Philipp Hertweck, Tobias Hellmund, Hylke van der Schaaf, Jürgen Moßgraber, Jan-Wilhelm Blume; Fraunhofer IOSB, Germany (ID 117) 1126

Robust Private Web Maps with Open Tools and Open Data; Bas Lijnse; Netherlands Defence Academy / Radboud University Nijmegen, The Netherlands (ID 135) 1140

EMAssistant: A Learning Analytics System for Social and Web Data Filtering to Assist Trainees and Volunteers of Emergency Services; Rahul Pandey, Gaurav Bahl, Hemant Purohit; George Mason University, United States of America (ID 163) 1151

WiPe papers
Evaluation Framework for the iTRACK Integrated System, Ahmed Abdeltawab Abdelgawad, Tina Comes; Centre for Integrated Emergency Management (CIEM), University of Agder, Norway (ID 129) 1160

Supporting firefighter training through visualising indoor positioning, motion and time use data; [1]Jo Dugstad [2]Wake, Barbara Wasson, [2]Edvard Pires Bjørgen, [2]Fredrik Vonheim Heimsæter; [1]NORCE, [2]SLATE-University of Bergen (ID) 1173

Track 13. Privacy Risk Management in Critical Infrastructures..... 1183

CoRe paper
Renouncing Privacy in Crisis Management? People's View on Social Media Monitoring and Surveillance; Larissa Aldehoff, Meri Dankenbring, Christian Reuter; Technische Universität Darmstadt, Science and Technology for Peace and Security (PEASEC) (ID 106) 1184

WiPe paper
Anonymizing Cybersecurity Data in Critical Infrastructures: The CIPSEC Approach; Ana Rodríguez-Hoyos[1,2], José Estrada-Jiménez[1,2], David Rebollo-Monedero[1], Jordi Forné[1], Rubén Trapero Burgos[3], Antonio Álvarez Romero[3], Rodrigo Diaz Rodríguez[3] ; [1]Universitat Politécnica de Catalunya (UPC), Barcelona, España; [2]Escuela Politécnica Nacional (EPN), Quito, Ecuador; [3]ATOS, Madrid, España (ID 199).. 1198

Track 14. Protecting Critical Infrastructures in Crisis Situations 1209

CoRe papers
Evaluating Critical Infrastructure Resilience via Tolerance Triangles: Hungarian Highway pilot case study; Laura Petersen[1,2], Eva Horvath[3], Johan Sjöström[4]; [1]Euro-Mediterranean Seismological Centre (EMSC); [2]French National Center for Scientific Research (CNRS); [3]Magyar Közút Nonprofit Zrt; [4]RISE Research Institutes of Sweden (ID 128) 1210

Enhanced Crisis-Preparation of Critical Infrastructures through a Participatory Qualitative-Quantitative Interdependency Analysis Approachd; Axel Dierich[1], Katerina Tzavella[2], Neysa Jacqueline Setiadi[2], Alexander Fekete[2] ; [1]inter 3 Institute for Resource Management, Germany· 2Technische Hochschule Köln, Germany (ID 144) 1226

WiPe papers
Choosing Ways to Increase Resilience in Critical Infrastructures; Sandra König; Austrian Institute of Technology, Austria (ID 178) 1245

Cascading Threats in Critical Infrastructures with Control Systems; Sandra König, Stefan Schauer; Austrian Institute of Technology, Austria (ID 197) 1252

On the usage of Virtual Reality for Crisis Management exercises in Critical Industrial Sites; Aurélie Congès[1], Frédérick Bénaben[1], Olivier Pierre[2], Francis Savic[3], Olivier Chabiron[2], Matthieu Lauras[1] ; [1]IMT Mines Albi, France; [2]Immersive Factory; [3]Report One (ID 258) 1260

Track 15. Open Track..... 1269

CoRe papers

Understanding Aggregate Human Behaviour Changes in Response to a Natural Disaster in Vanuatu via Mobile Network Data Analysis; Rajius Idzalika, Yulistina Riyadi, Imaduddin Amin, George Hodge, Jong Gun Lee; Pulse Lab Jakarta, Indonesia (ID 123) 1270

*First In, Left Out : Current Technological Limitations from the Perspective of Fire Engine Compa*nies; Katelynn Amaris Kapalo, Pamela Wisniewski, Joseph J. LaViola Jr.; University of Central Florida, United States of America (ID 156) 1286

WiPe papers

Design and development methods for improving acceptance of IT among emergency responders; Erion Elmasllari; Fraunhofer FIT, Germany (ID 107) 1300

Structured crisis training with mixed reality simulations; Jo Erskine Hannay, Yelte Kikke; Univeristy of Oslo, Norway (ID 157) 1310

Challenges and Trends of Data Management for Firefighting in Germany and the Netherlands; Kevin Wesendrup, Nicola Rupp, Adam Widera, Bernd Hellingrath; University of Münster, Germany (ID 165) .. 1320

The Influence of Swift Trust on Virtual Team's Sensemaking in Crisis: A Research Model; Xiaodan Yu[3], Deepak Khazanchi[1,2] ; [1]University of Nebraska Omaha, USA; [2]Center for Integrated Emergency management (CIEM), University of Agder, Norway; [3]University of International Business & Economics, Beijing, China (ID 166) 1330

Dark Web, Black Markets: The Utility of Dark in Disaster Recovery Research; Kathleen Ann Moore; James Madison University, United States of America (ID 182) 1337

Integrating citizen initiatives in a technological platform for collaborative crisis management; Robin Batard[1,2], Aurélie Montarnal[2], Frédérick Benaben[2], Caroline Rizza[1], Christophe Prieur[1], Andrea Tapia[3]; [1]Telecom ParisTech; [2]IMT Mines Albi; [3]The Pennsylvania State University (ID 259) 1346

Sharing Incident and Threat Information for Common Situational Understanding; Bjørn Erik Munkvold[1], Jaziar Radianti[1], Jan Ketil Rød[2], Tomasz Opach[2], Mikael Snaprud[3], Sofie Pilemalm[4], Deborah Bunker[5] ; [1]CIEM, University of Agder; [2]Norwegian University of Science and Technology; [3]Tingtun AS; [4]CARER Linköping University; [5]University of Sydney (ID 260) 1357

Posters & Demos 1364

Towards proactive agility of crisis response; Anne-Marie Barthe-Delanoë[1], Audrey Fertier[2]; [1]Laboratoire de Génie Chimique, Université de Toulouse, CNRS, INPF, UPS, Toulouse, France; [2]Centre de Génie Industriel, IMT Mines Albi, Albi, France (ID p238) 1365

The Search for Embeddedness: Leveraging Scientific Modeling in Disaster Response; Theresa Jefferson[1], John R. Harrald[2] ;[1]Loyola University Maryland, USA;[2]Virginia Tech, USA (ID p342) 1367

LETSCROWD: Dynamic Risk Assessment for Mass Gatherings; Carlo Dambra[1], Alex Gralewski[2], Jordi Arias[3] *;* [1]ZenaByte s.r.l.,Italy, [2]PROPRS Ltd., United Kingdom [3]ETRA I+D S.A., Spain (ID p308) 1369

Comparative Study of Feature Representations for Disaster Tweet Classification; Pallavi Jain[1], Bianca Schoen-Phelan[1], Robert Ross[1] ; [1]Technological University Dublin, Ireland (ID p310) 1371

Collaboration in Emergency Response Drills: an Experience with Firefighters; Paulo Victor R. de Carvalho[1], Angela W. Righi[2], Gilbert J. Huber[3], Jose Orlando Gomes[3] ; [1]Instituto de Engenharia Nuclear Brasil; [2]Universidade de Santa Maria, Brasil; [3]Universidade Federal do Rio de Janeiro, Brasil (ID p301)... 1373

Evaluating the Performance of Deep Learning Methods for Hurricane-Related Image Classification; Matthew Johnson[1], Dhiraj Murthy[1], Brett W. Robertson[1], William Roth Smith[1], Keri K. Stephens[1] ; [1] The University of Texas at Austin (ID p305) 1375

Multi-agent planning and execution with risk analysis and multi-criteria optimization: the case of rescue plans to environmental and humanitarian crisis; Cendrella CHAHINE[1,2], Thierry VIDAL[2], François PERES[2], Mohamad El FALOU[1] ; [1]ULF Tripoli (Université de Technologie et de Sciences Appliquées Libano-Française), Lebanon; [2]LGP-ENIT (Le Laboratoire Génie de Production de l'École Nationale d'Ingénieurs de Tarbes), France (ID p311) 1377

CroMa – Crowd Management in Trans-portation Infrastructures; Alexander Gabriel[1], Andreas Lotter[1], Frank Fiedrich[1] ; [1]University of Wuppertal (ID p306) 1379

Towards Bridging the Gap between Demand and Supply in Humanitarian Geodata Use; Melanie Eckle[1], Sven Lautenbach[1], Alexander Zipf[1] ; [1]GIScience Research Group, Institute of Geography, Heidelberg University, Germany (ID p331) 1381

Geographic and Content-Based Prioritization of Tweets for Emergency Response: The Cases of Weather-Related Disaster Events; A. Marcela Suarez, Keith C. Clarke; University of California, Santa Barbara; USA (ID p340) 1383

Serious gaming for training non-technical skills in crisis management and emergency response; Isabelle Turcotte[1], Gabrielle Teyssier-Roberge[1], Rego Granlund[2], Sébastien Tremblay[1] ; [1]Laval University, France, [2]RISE Research Institutes of Sweden (ID p303a) 1385

A comparison of two methodologies to assess shallow landslide risk; Erica Akemi Goto[1], Keith Clarke[1] ; [1]University of California, Santa Barbara (ID p316) 1387

Analysis of Japanese Tweets about 2018 Typhoon Jebi by Creating Co-occurrence Networks; Sanetoshi Yamada; Keisuke Utsu , Osamu Uchida; Tokai University (ID p225) 1391

Standardization for an enhanced crisis management; René Lindner; DIN, Germany (ID p309) 1393

Constructing Trust in Disaster Communications; Yuko Murayama; Tsuda University, Japan (ID p154) ... 1395

Gathering Local Knowledge for Disaster Risk Reduction: The Use of Sketch Maps in Group Discussions; Carolin Klonner, Luca Blessing; Institute of Geography, Heidelberg, Germany (ID p348) 1397

Towards a comprehensive architecture to extract situational models from Twitter data; Julien COCHE[1], Aurelie MONTARNAL[1], Andrea TAPIA[2], Frederick BENABEN[1]; [1]IMT Mines Albi, France; [2]PennState University, USA (ID p315) 1399

A Filtering and Visualization Workbench for Messages in Crisis Management; Jan Blume, Philipp Hertweck, Tobias Hellmund, Jürgen Moßgraber; Fraunhofer IOSB, Germany (ID p303) 1401

Distributed Learning Automata-based Intelligence for Propagation-based Fake News Detection on Social Media During Crisis; Ahmed Abouzeid[1,2], Ole-Christoffer Granmo[1,2], Christian Webersik[1,2], Morten Goodwin[1,2]; [1]University of Agder, Norway; [2]Center of Integrated Emergency Management (CIEM), Norway (ID p312) 1403

Analysis of Tweets with Rescue Request Hashtags in The 2018 Japan Floods; Shuji Nishikawa, Osamu Uchida, Keisuke Utsu; Tokai University, Japan (ID p102) 1405

Social Media in Disaster Management: Exploring the Information Exchange Behavior in the Underserved Communities; Thiagarajan Ramakrishnan, Louis Ngamassi, Shahedur Rahman; Prairie View A&M University, USA (ID p314) 1407

AIOSAT - Autonomous Indoor & Outdoor Safety Tracking System; Iñigo Adin[1], Bart Scheers[2], Jose Manuel Sanchez[3], Javier Ferreira[4], Berend Jan van der Zwag[5], Didier de Wulf[6], Ymko Attema[7] ; [1]CEIT, Spain, [2]RMA, Belgium, [3]INTEGRASYS, Spain, [4]SAXION, Netherlands, [5]INERTIA, Netherlands, [6]Hulpverleningszone Centrum, Belgium, [7]Twente Safety Campus, Netherlands (ID p304) 1409

Towards a privacy aware information system for emergency response; Alba Morales, Enrico Daga, Enrico Motta; The Open University, United Kingdon (ID p309) 1411

Mission Track: Plans into Actions; Víctor A. Bañuls[1], Jaime E. del Palacio[2], Eduardo del Palacio[2], Fernando Tejedor[2]; [1]Universidad Pablo de Olavide, Spain; [2]Mission Track, Spain (ID d001) 1414

ISCRAM 2019: Towards individual-centric emergency management systems

The theme of ISCRAM 2019 is *"Towards individual-centric emergency management systems"*. This edition wishes to highlight the particular needs of the individual stakeholder in Crisis and Emergency Management and to stimulate discussions that enable the design of individual-centric crisis and emergency management systems.

As anchors to this year's program we have three keynote speakers, (1) Marcos Bruna, MD, PhD, Hospital Universitario y Politécnico La Fe, València (Spain) who will present "Transplantation: the Spanish Model in a World of Challenges", (2) Steve Peterson, CEM®, National Institutes of Health. Bethesda, MD (USA), who will present "Addressing Complexities of Disaster Social Media Analysis" and (3) Dr. Monika Büscher, Professor of Sociology, Director of the Centre for Mobilities Research and Associate Director for the Institute for Social Futures, Lancaster University, UK who will present "Making IT Personal: Radically Reflexive Resilience."

In addition to these focal points we also have a panel on "Research Meets Practice", with two practitioners (Jennifer Chan, Northwestern Memorial Hospital, Chicago, IL, USA; and Steve Peterson, National Institutes of Health, Bethesda, MD, USA) and two researchers (Caroline Rizza, Economic and Social Sciences Department of Télécom Paristech, France; and Marcos Borges, Federal University of Rio de Janeiro, Brazil). The panel will be chaired by Valérie November, Director of Research, Technical Laboratory, Territories and Society, École des Ponts, University Paris, France.

We are pleased to present the accepted papers for ISCRAM 2019, which represent excellent contributions to a wide range of topics related to the use of information for the full cycle of emergency management.

The overall acceptance rate for the Completed Research (CoRe) papers at the conference was 60%.

- 59 CoRe papers were submitted, 35 were accepted
- 19 CoRe submissions were recommended as WiPe papers (Rejected)
- 7 CoRe submissions were suggested for consideration as a poster only (Rejected)
- 1 paper was withdrawn

The overall acceptance rate for the Work in Progress (WiPe) papers at the conference was 74%.

- 95 WiPe papers were submitted, 70 were accepted
- 25 WiPe submissions were rejected, or rejected with the suggestion for poster consideration

The program is completed with 22 posters and one demonstration.

For this year, ISCRAM defined two types of paper: Research and Insight. Research papers are intended to meet the needs of researchers by being peer reviewed to the highest academic standards. The primary aim of an academic paper is to contribute to the scientific body of knowledge. By contrast, Insight papers are intended to meet the needs of practitioners, managers, professionals, experts, and policy makers by being peer reviewed to high practical standards. The primary aim is to give an insight into what real-world problems arise during emergencies, disasters, and crises, and how such problems can be solved with the help of information systems.

The same five criteria (relevance, significance, originality, validity, and clarity) were used to judge all types of ISCRAM papers whether the paper is Research or Insight. However, some of these criteria are defined differently between Research and Insight papers.

Researchers and practitioners submitted to a range of topic areas including: Analytical Modeling and Simulation; Command and Control Studies; Ethical, Legal, and Social Issues (ELSI); Logistics and Supply Chain Management in Crisis Response; Intelligent and Semantic Web Systems; Geospatial Technologies and Geographic Information Science for Crisis Management; Planning, Foresight, and Risk Analysis; Social Media in Crises and Conflicts; Universal Design of ICT in Emergency Management – Identifying and Addressing ICT Challenges Faced by Elderly and People with Disabilities; Knowledge, Semantics and AI for Risk and Crisis Management; Community Engagement and Healthcare Systems; Tool Talks; Privacy Risk Management in Critical Infrastructures; and Protecting Critical Infrastructures in Crisis Situations. Research that did not fall under these specific areas were applied broadly to the Open Track.

Both Research and Insight papers were submitted in Full (CoRe) or Short (WiPe) form. A full paper reports on a completed project or piece of work, including validation of the results. Only full papers may be candidates for selection for the Best Research Paper, Best Student Paper, and Best Insight Paper awards.

By contrast, a short paper is intended for the reporting of part of a complete project or piece of work. For example, a short paper may describe a project or research plan, a literature survey, the design of an information system, the development and testing of software, user evaluation of developed software, deployment, a real incident, a proposed new policy.

All authors of the papers in these proceedings have agreed to the ISCRAM2019 Proceedings copyright agreement. This copyright agreement and use license state that an author retains copyright. It also permits any user – for any non-commercial purpose, including unlimited classroom and distance learning use – to download, print out, extract, archive, distribute and make derivative works of an article published in the ISCRAM2019 Proceedings, as long as appropriate credit is given to the authors and the source of the work and all derivative works are placed under the same license.

Lastly, the program co-chairs and the local chair wish to thank the track chairs, the reviewers and the ISCRAM board for offering their full participation in the body of this work.

We hope that you enjoy what we expect to be a lively conference!

ISCRAM2019 Program and Organization Chairs

Scientific Committee

Program Committee Chairs

José J. González, *University of Agder, Norway*

Zeno Franco, *Médical College of Winconsin, USA*

Workshops Chairs

Jaziar Radianti, *University of Agder, Norway*

Hemant Purohit, *George Mason University, USA*

Demo & Poster Chairs

Josune Hernantes, *Tecnun, University of Navarra, Spain*

Leire Labaka, *Tecnun, University of Navarra, Spain*

Doctoral Colloquium Chairs

Kathleen Moore, *James Madison University, USA*

Aurélie Montarnal, *IMT Mines Albi, France*

Proceedings Chair

Mª Carmen Penadés, *Universitat Politècnica de València, Spain*

Link with ISCRAM

Caroline Rizza, *Télécom ParisTech, France*

Awards Chair

Hans-Jochen Scholl, *University of Washington, USA*

Organization Committee

Organization Chair

José H. Canós, *Universitat Politècnica de Valencia (UPV), Spain*

Committee

José A. Carsí, *UPV, Spain - General Coordinator*

Francisco de Zulueta, *UPV, Spain - Website Design & Management*

Ana G. Núñez, *UPV, Spain - Website Design & Management*

Juan Sánchez Díaz, *UPV, Spain - ConfTool*

Fanny Collado, *UPV, Spain - Conference Office*

Ester Srougi, *UPV, Spain - Conference Office*

Mª Carmen Penadés, *UPV, Spain - Volunteer Coordinator*

Organized by

Sponsored by

Invited Talks

Transplantation: The Spanish Model in a World of Challenges

Marcos Bruna, MD, PhD, *Hospital Universitario y Politécnico La Fe, València, Spain*

ABSTRACT. Transplantation could be defined as the process of taking an organ or tissue from somebody and implanting it in another part of the body or in another body. The history of transplantation is long and sometimes unsuccessful and difficult to understand, but year to year surgical technology, improvements in intensive care facilitated better results.

Spain has been a world leader in transplantation for the last 26 years, with near to 50 donors per million of population and, for instance, more than 5,000 organs transplanted during 2017. These numbers are achieved thanks principally to the generosity of donors and their families, and also to the capacity of the Spanish Transplantation System (STS) to cope with the emergency that the existence of a new donor represents.

The STS, also known as the "Spanish Model", is built on top of a complex organization with great profitability. Team work, education, professional training, registration, reward and security are some of the keys to its success and export to other countries. But, above all, there is no success without donors: we need donors to give an opportunity to people waiting for a new organ to continue living. The characteristics of donors and recipients have changed during the last decades, and so the methods have evolved, too.

In order to maintain this model´s efficiency and its high survival rates, it is necessary to incorporate different approaches, treatments, advanced knowledge and new technologies like artificial intelligence in this medical practice. In this talk, we will review the latest advances in the last decades. We will also outline what are the challenges open, and how the ISCRAM community of researchers and practitioners can play a key role in the overall process. The future will be exciting because there are many opportunities and new ways to explore to optimize the results of transplantation programs.

ABOUT THE SPEAKER. Marcos Bruna is a Specialist Surgeon in the General and Digestive Surgery Service at the "Hospital Universitario y Politécnico La Fe", in València since March 2019. Before joining this service, he worked in a similar position at the "Hospital General Universitario de València", where he was also Coordinator of the Transplantation Unit (2013-2019). He holds a degree in Medicine (Universidad Autónoma de Madrid, 2003) and a Doctorate in Medicine (Universitat de València-Estudi General, 2015). In his work, he has applied advanced AI techniques to support the selection of the best recipient for

an organ. Marcos is member of several international associations, and has participated in numerous technical and administrative committees at local, national and international levels.

Addressing Complexities of Disaster Social Media Analysis

Steve Peterson, CEM®, *National Institutes of Health, Bethesda, MD, USA*

ABSTRACT. Citizen reliance on social media during disasters has increased in recent years. As global acceptance and adoption of social media by practitioners continues to grow, dependable solutions for employing social media during disasters remain elusive. There is a dimension that increasing citizen reliance on social media implies more demand from citizens that practitioners respond to social media during disasters. In the face of difficulties compounded by limited personnel availability and data dynamics driven by the type, scope, magnitude, and severity of the disaster, practitioners seek evidence on how to more effectively tackle these challenges and ultimately develop sound social media operational procedures.

The presentation will include a scenario which examines real world social media analytical complexities from past disasters. The scenario will also highlight the potential risks involved in coordinating across multiple agencies and volunteer organizations. This is especially germane when social media analytics surface time-sensitive actionable intelligence, such as social media calls for help.

The research community continues to conduct valuable retrospective disaster research, and carry out respected studies, on the use of social media. These efforts raise awareness of the value social media provides practitioners during disasters. The presentation will conclude by revisiting the scenario and examining sample research questions that highlight underexplored areas. Further examination of these issues may lead to unique findings that are more informative than those tendered by standard retrospective research.

By establishing mutually beneficial collaborative relationships, practitioners and researchers could gain enhanced insights into social media analytical complexities experienced during disasters. And this might well form the basis for future joint research in this area of concentration.

ABOUT THE SPEAKER. Steve Peterson is a Certified Emergency Manager (CEM) employed at the National Institutes of Health. He serves as the Chair of the Department of Homeland Security' s (DHS) Social Media Working Group for Emergency Services and Disaster Management. His professional specialization has focused on emergency communications policy development in both the public and private sectors, including authoring the Current and Future State of Emergency Communication sections of the

DHS National Emergency Communications Plan. He has spoken to local, national, and international audiences exploring various dimensions of social media phenomena. His conceptualizations address not only the current state of social media, but its unrealized potential to impact the effectiveness of emergency operations. Steve has also served as president of the Montgomery County, Maryland Community Emergency Response Team (CERT). Under his leadership this team received international recognition for its efforts in providing surge support in determining situational ground truth for Cyclone Pam damage (near Australia) and the notorious 7.9 Nepal earthquake. Steve received his Bachelor of Science degree in Computer Studies from the University of Maryland and attained his Certified Emergency Manager designation from the International Association of Emergency Managers.

Making it Personal: Radically Reflexive Resilience

Monika Büscher, *Lancaster University, UK*

ABSTRACT. The 21st Century has been labelled the century of disasters. Yet individuals and societies are doing too little, too late to prepare for or prevent disasters. One reason is a lack of personalisation. People do not feel that disasters will affect them. This is particularly true with regard to slow-motion disasters such as climate change, biodiversity loss, soil erosion, or antimicrobial resistance, but acute emergency warnings and evacuation orders can also be met by optimistic bias ('It won't happen to me/here'). Personalisation and intelligent context-driven computing can triangulate personal risk factors (such as location and vulnerability) with predictive disaster risk data to dynamically issue personalised warnings and guidance. It can save lives. However, a 'solutionist' turn to computational personalisation could further entrench problematic patterns of disaster risk governance and a false sense of security.

As the Anthropocene unfolds, many slow-motion disasters are producing more, and more intense, acute disasters, from extreme weather to epidemics. These arise from the cumulative personal lives of 7.7 billion humans, with risks highly unequally distributed. In this talk, I show that attention to grassroots creativity that makes responsibility for risk and risk governance personal can enhance communities' capacity to live well with risk. Technologies of participation that support crisis informatics, citizen science, and collective intelligence, for example around environmental monitoring, can join with efforts of personalisation. By delineating hopeful projects that develop technologies of humility, we can widen the scope for innovation and raise the bar of ambition for personalised and context-driven computing to support radically reflexive resilience.

ABOUT THE SPEAKER. Monika Büscher is Professor of Sociology at Lancaster University in the UK, Director of the Centre for Mobilities Research. She is the academic lead for the UK ESRC Social Research Impact Accelerator Account at Lancaster University (2019-2022) and leads research on social practices of mobility and risk governance in a range of projects, e.g. isITethical? (2017-2018), SecInCoRe (2014-2017), BRIDGE (2011-2015).

Monika initiated the www.isITethical.eu platform, which develops guidance for digital ethics and responsible innovation in collaboration with the Public Safety Communications Europe Network. She received an honorary doctorate from Roskilde University, Denmark for her work on participatory design. She edits the book series Changing Mobilities (Routledge) with Peter Adey.

Professional Day – Panel "Research meets practice"

Two practitioners and two researchers brainstorm needs, challenges and opportunities for practice-oriented research.

Practitioners:

Jennifer Chan, *MD, MPH Director, Global Emergency Medicine, Northwestern Memorial Hospital, US Chicago, IL, USA*

Steve Peterson, *Emergency Management Specialist, Division of Emergency Management, National Institutes of Health, Bethesda, MD, USA*

Researchers:

Caroline Rizza, *Associate Professor in Information and Communication Sciences, Economic and Social Sciences Department of Télécom Paristech, Paris, France*

Marcos Borges, *Professor at the Federal University of Rio de Janeiro, Department of Computer Sciences, Rio de Janeiro, Brazil*

The panel will be facilitated by Valérie November, *Director of Research, Technical Laboratory, Territories and Society, Ecole des Ponts, University Paris, France.*

Workshops

The aim of the ISCRAM 2019 Workshops is to allow researchers, technologists, practitioners as well as the representatives from funding agencies to host a dedicated session on the specific, emerging topics for crisis management and related technologies.

WS1. Encouraging Productive Interaction between Practitioners and Researchers

This workshop will bring together practitioners and researchers to identify and brainstorm solutions to the obstacles that impede better interaction between the two groups. The goal is to arrive at a small number of collaborative projects around which groups of practitioners and researchers would work together.

Organized by:

Edward G. Happ, *University of Michigan, USA*

Andrea H. Tapia, *Penn State University, USA*

Format: Researcher-Practitioners dialogue

WS2. Incorporating social media analysts in emergency dispatch centers

The workshop will bring together international practitioners and researchers in the global emergency dispatch community for discussions opportunities, challenges, and best practices for incorporating social media analytics and analysts in emergency dispatch centers.

Organized by:

Rob Grace,*Penn State University, USA)*

Lieutenant colonel Olivier Galichet, *DGSCGC, Ministère de l'Interieur, France*

Caroline Rizza, *Télécom Paristech, France*

Format: Semi Tutorial, Researcher-Practitioners dialogue

WS4. 2nd International Workshop on Intelligent Crisis Management Technologies for climate events -ICMT

Organized by:

Anastasios Karakostas, *Information Technologies Institute, Greece*
Claudio Rossi, *Istituto Superiore Mario Boella, Italy*
Evangelos Sdongos, *Institute of Communication and Computer Systems, Greece*
Angelos Amditis, *Institute of Communication and Computer Systems, Greece*

Format: Semi Tutorial

WS5. Physical and cyber threats: the new challenges for TLC Critical Infrastructures

Organized by:

Federica Battisti, *Roma Tre University, Italy*

Federica Pascucci, *Roma Tre University, Italy*

Format: Semi Tutorial

Track Chairs

Track 1. Analytical Modeling and Simulation

Christopher Zobel, *Virginia Tech, USA*

Josey Chacko, *Mount St. Mary's University, USA*

Track 2. Command and Control Studies

Björn JE Johansson, *Linköping University, Sweden*

Peter Berggren, *Linköping University, Sweden*

Nicoleta Baroutsi, *Swedish Defence University*

Track 3. Ethical, Legal and Social Issues

Monika Büscher, *Lancaster University, UK*

Katrina Petersen, *Trilateral Research, TLD*

Caroline Rizza, *Télécom Paristech, Paris, France*

Track 4. Logistics and Supply-Chain Management in Crisis Response

Bernd Hellingrath, *University of Muenster, Germany*

Gyöngyi Kovács, *Hanken University, Finland*

Adam Widera, *University of Muenster, Germany*

Track 5. Intelligent and Semantic Web Systems

Julie Dugdale, *University Grenoble Alps, France*

Fiona McNeill, *Heriot-Watt University, UK*

Francisco José Quesada Real, *University of Edinburgh, UK*

Hemant Purohit, *George Mason University, USA*

Track 6. Geospatial Technologies and Geographic Information Science for Crisis Management (GIS)

João Porto de Albuquerque, *University of Warwich, UK*

Alexander Zipf, *University of Heidelberg, Germany*

Flávio E. A. Horita, *Federal University of ABC, Brasil*

Track 7. Planning, Foresight and Risk Analysis

Murray Turoff, *New Jersey Institute of Technology, USA*

Victor A. Bañuls, *Pablo de Olavide University, Spain*

Track 8. Social Media in Crisis and Conflicts

Starr Roxanne Hiltz, *New Jersey Institute of Technology, USA*

Amanda Lee Hughes, *Brigham Young University, USA*

Imran Muhammad, *Qatar Computing Research Institute, Qatar*

Christian Reuter, *Technische Universität Darmstadt, Germany*

Track 9. Universal Design of ICT in Emergency Management

Terje Gjøsæter, *Oslo Metropolitan University, Norway*

Jaziar Radianti, *University of Agder, Norway*

Weiqin Chen, *Oslo Metropolitan University, Norway*

Erion Elmasllari, *Fraunhofer Fit Institute Bonn, Germany*

Track 10. Knowledge, Semantics and AI for Risk and Crisis Management

Hedi Karray, *INP-ENIT, University of Toulouse, France*

Antonio De Nicola, *ENEA, Italy*

Nada Matta, *Université de Technologie de Troyes, France*

Track 11. Community Engagement & Healthcare Systems

Zeno Franco, *Medical College of Wisconsin, USA*

Bas Linjse, *Radboud University, Netherlands*

Reem Abbas, *Auckland University of Technology*

Sheikh Iqbal Ahamed, *Marquette University, USA*

Track 12. Tool Talks

Bas Linjse, *Radboud University, Netherlands*

Jürgen Moβgraber, *Fraunhofer IOSB, Germany*

Anastasios Karakostas, *Centre for Research and Technology Hellas*

Track 13. Private Risk Management in Critical Infrastructures

Jordi Forné Muñoz, *Universitat Politècnica de Catalunya, Spain*

Javier Parra Arnau, *Universitat Rovira i Virgili, Spain*

Track 14. Protecting Critical Infrastructures in Crisis Situations

Stefan Schauer, *Austrian Institute of Technology*

Stefan Rass, *Alpen-Adria-Universität Klagenfurt*

Track 15. Open Track

José J. González, *University of Agder, Norway*

Hossein Baharmand, *University of Agder, Norway*

Reviewers

Abbas, Reem Abubakr
Adam, Carole
Adrot, Anouck
Alam, Firoj
Alimohammadi, Negin
Al-Olimat, Hussein
Alspach, Andrew
Andersen, Per-Arne
Anderson, Jennings
Anderson, Lauren Christine
Antunes, Pedro
Araujo Pessoa, Luis Filipe
Arnette, Andrew
Assis,Luiz Fernando Ferreira
Gomes Aupetit, Michael
Backfried, Gerhard
Baghersad, Milad
Baharmand, Hossein
Bañuls, Victor
Baroutsi, Nicoletta N.
Barrera, Gabriela Catalina
Bella, Gábor
Benaben, Frederick
Berggren, Peter
Bernardi, Ansgar
Betke, Hans
Blume, Jan-Wilhelm
Boersma, Kees
Borges, Marcos
Bowden, Zeb
Braun, Andreas
Bubbich, Carsten
Bubendorff, Sandrine
Bull, Maria Teresa
Bundy, Alan
Campelo, Claudio
Caragea, Doina
Caragea, Cornelia
Carlerby, Mats
Carr, Aline
Carvalho, Paulo Victor
Castor, Martin
Castro Degrossi, Livia
Chacko, Josey
Chae, Junghoon
Chan, Jennifer Lisa
Chen, Weiqin
Chen, Lixiong
Chen-Burger, Jessica
Collignon, Stephane
Comes, Tina
Comunello, Francesca
Dailey, Dharma
De Nicola, Antonio
Deane, Jason
Delatour, Guillaume
Diamantini, Claudia
Dierich, Axel
Dokas, Ioannis
Dorasamy, Magiswary
Dugdale, Julie
Easton, Catherine Rachel
Ehnis,Christian
Ekbal, Asif
Erskine, Michael
Estrada-Jimenez, Jose
Fischer, Diana
Fonio, Chiara
Forné, Jordi
Franco, Zeno
Ganji, Abbas
Gargouri, Fa·ez
Ghosh, Saptarshi
Giannakeris, Panagiotis
Gjøsæter, Terje
Gonzalez, Jose J.
Goto, Erica Akemi
Grace, Rob
Graham, Catherine
Granholm, Martina
Gurczik, Gaby
Hadfi, Rafik
Hadgu, Asmelash Teka
Halse, Shane Errol
Han, Sooji
Haselkorn, Mark P
Heaslip, Kevin
Heldal, Ilona
Hernantes, Josune
Hiltz, Starr Roxanne
HO, Hoang Nam
Horita, Flávio
Hughes, Amanda Lee
Imran, Muhammad
Jafari, Raheleh
Jansen, Jan Martin
Jefferson, Theresa
Johansson, Björn Johan Erik
Jonson, Carl-Oscar
Karagiannis, Dimitris
Karakostas, Anastasios
Kåreklint, Lars
Karray, Hedi
Kassel, Gilles
Kaufhold, Marc-André
Kavanaugh, Andrea L
Khansa, Lara
Klein, Stefan
Klonner, Carolin
Kogan, Marina
Kropczynski, Jess
Kumar, Ajay
Lalone, Nicolas
Lamine, Narjes
Lamothe, Jacques
Lanfranchi, Vitaveska
Lechtenberg, Sandra
Li, Liuqing
Lijnse, Bas
Lindner, Sebastian
Lorini, Valerio
Lyuba, Mancheva
Majchrzak, Tim A.
Martinez, Santiago
Matheson, Lance
Matta, Nada
McNeill, Fiona Jennet
Meesters, Kenny
Melchiori, Michele
Memon, Muhammad Ali
Mentler, Tilo
Mercier Laurent, Eunika
Mirbabaie, Milad
Missier, Paolo
Mitra, Prasenjit
Montarnal, Aurélie
Moore, Kathleen Ann
Moreira, Joao
Moßgraber, Jürgen
Moura, Rodolfo
Munkvold, Bjørn Erik
Münzberg, Thomas
Musaev, Aibek
Nespexa, Vittorio
NilssonHelene
Noori, Nadia
NorlanderArne
OfliFerda, Daniel
Opdahl, Andreas Lothe
Osaragi, Toshihiro
Oskarsson, Per-Anders
Ottenburger, Sadeeb
Pamukcu, Duygu
Parra-Arnau, Javier
Penadés, M.Carmen
Pernici, Barbara
Petersen, Katrina
Petersen, Laura Anne
Peterson, Steve
Petrie, Charles J
Pettersson, John Sören
Piedrahita, Diego
Pipek, Volkmar
Plotnick, Linda
Power, Robert Andrew
Prytz, Erik
Purohit, Hemant
Quesada, Francisco José
Rabah, Mourad
Radianti, Jaziar
Ramirez, Miguel
Rass, Stefan
Resch, Bernd
Reuter, Christian
Rizza, Caroline
Rossi, Claudio
Roy Chowdhury, Soudip
Rudra, Koustav
Rupp, Nicola
Russell, Robin
Sabou, John
Sakurai, Mihoko
Sanchez Diaz, Juan
Santos, Leonardo
Schauer, Stefan
Scholl, Hans Jochen
Schwartz, David G.
Seref, Michelle
Serre, Damien

Sharpanskykh, Alexei
Sheetz, Steven
Shen, Ruiqi
Shibuya, Yuya
Simanjuntak, Humasak
Tommy Argo, Xuan
St. Denis, Lise Ann
Starbird, Kate
Stephens, Keri K.
Stötzer, Johanna
Surakitbanharn, Chittayong
Sutton, Jeannette
Svenmarck, Peter
Taglino, Francesco
Tan, Marion Lara
Tapia, Andrea
Tate, Austin
Tehler, Henrik
Tellioglu, Hilda
Thevin, Lauren
Thom, James Allan
Timm, Ingo J.
Toepke, Samuel Lee
Tsui, Eric
Turoff, Murray
Uchida, Osamu
Uddin, Ajim
Ulbrich, Philipp
Utsu, Keisuke
van Laere, Joeri
Vargas, Jorge
Villani, Maria Luisa
Villela, Karina
Vinhas, Lubia
Vitiugin, Fedor
Voisard, Agnès
Watson, Hayley
Widera, Adam
Wienen, Hans Christian
Wiens, Marcus
Wik, Malin
Winstanley, Peter
Wolbers, Jeroen
Yang, Liang Emlyn
Yang, Lili
Zamora, Jennifer
Zhu, Min
Zobel, Christopher William
Zulean, Marian

ISCRAM 2019 Best Paper Awards

The conference organization will award most meritorious papers in three categories:

(1) Best CoRe Paper

(2) Best Insight Paper

(3) Best Student Paper

Chair: Hans Jochen Scholl, *University of Washington, USA*

Committee: Frédérick Bénaben, *École des Mines d'Albi-Carmaux, France*

Julie Dugdale, *Université Grenoble Alpes, France*

Christopher Zobel, *Virginia Tech, USA*

Mihoko Sakurai, *International University of Japan, Japan*

Best CoRe Paper Award

Integrating Social Media into a Pan-European Flood Awareness System: A Multilingual Approach, Valerio Lorini, Carlos Castillo, Francesco Dottori, Milan Kalas, Domenico Nappo and Peter Salamon

Best CoRE Paper Nominees:

- *Integrating Social Media into a Pan-European Flood Awareness System: A Multilingual Approach,* Valerio Lorini, Carlos Castillo, Francesco Dottori, Milan Kalas, Domenico Nappo and Peter Salamon
- *Simulation Analysis of Fire Hydrant Usability Levels after Large Earthquake*, Toshihiro Osaragy and Noriaki Hirokawa
- *The Dynamics of Cyber Resilience Management*, Juan Francisco Carías, Leire Labaka, José María Sarriegi, Andrea Tapia and Josune Hernantes
- *CrisisDPS: Crisis Data Processing Services*, Firoj Alam, Muhammad Imran and Ferda Ofli

Best Insight Paper Award

Identifying Disaster Damage Images Using a Domain Adaptation Approach, Xukun Li, Doina Caragea, Cornelia Caragea, Muhammad Imran and Ferda Ofli

Best Insight Paper Nominees:

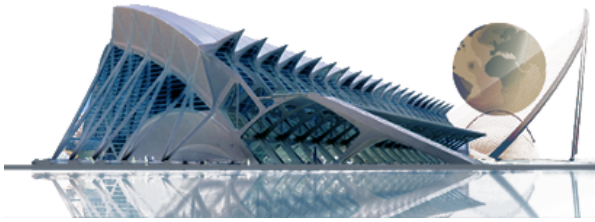
- *Identifying Disaster Damage Images Using a Domain Adaptation Approach*, Xukun Li, Doina Caragea, Cornelia Caragea, Muhammad Imran and Ferda Ofli
- *Management of Sensor Data with Open Standards*, Philipp Hertweck, Tobias Hellmund, Hylke van der Schaaf, Jürgen Moβgraber and Jan Blume
- *Opportunistic Affiliation in Spontaneous Volunteer Management*, Daniel Auferbauer, Roman Ganhör and Hilda Tellioğlu
- *Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios*, Sebastian Lindner, Stefan Sackmann and Hans Betke

Best Student Paper Award

Simulation Platform for Unmanned Aerial Systems in Emergency Ad Hoc Networks, Patrick Lieser, Julian Zobel, Björn Richerzhagen and Ralf Steinmetz

Best Student Paper Nominees:

- *Challenges in Community Resilience Planning and Opportunities with Simulation Modeling*, Abbas Ganji, Negin Alimohammadi and Scott Miles
- *Simulation Platform for Unmanned Aerial Systems in Emergency Ad Hoc Networks*, Patrick Lieser, Julian Zobel, Björn Richerzhagen and Ralf Steinmetz
- *Combining a social science approach and GIS-based simulation to analyse evacuation in natural disasters: A case study in the Chilean community of Talcahuano*, Susanne Kubisch, Johanna Stötzer, Sina Keller, María T. Bull and Andreas Braun
- *Detecting Disaster Recovery Activities via Social Media Communication Topics*, Yaya Shibuya and Hideyuki Tanaka



ISCRAM 2019
16 TH INTERNATIONAL CONFERENCE ON INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

Track 1.

Analytical Modeling and Simulation

Chairs

Christopher Zobel, *Virginia Tech, USA*

Josey Chacko, *Mount St. Mary's University, USA*

Reliability of expert estimates of cascading failures in Critical Infrastructure

Ahmed A. Abdelgawad
Centre for Integrated Emergency Research,
University of Agder, Norway
ahmed.aboughonim@uia.no

Jose J. Gonzalez
Centre for Integrated Emergency Research,
University of Agder, Norway
josejg@uia.no

ABSTRACT

Owing to the complexity of Critical Infrastructures and the richness of issues to analyze, numerous approaches are used to model the behavior of CIs. Organizations having homeland security as mission often conduct desktop-based simulations using judgmental assessment of CI interdependencies and cascading failures. Expert estimates concern direct effects between the originally disrupted CI sector and other sectors. To better understand the magnitude of aggregate cascading effects, we developed a system dynamics model that uses expert estimates of cascading failures to compare the aggregate effect of cascading failures with the primary direct cascading failures. We find that the aggregate effect of compounded cascading failures becomes significantly greater than the primary cascading failures the longer the duration of the original disruption becomes. Our conceptually simple system dynamics model could be used to improve desktop-based exercises, since it illustrates consequences that go beyond judgmental assessment.

Keywords

Critical Infrastructure, Cascading failures, Expert assessment, Desktop exercise, Tabletop exercise, Modeling and simulation, Dynamic complexity

INTRODUCTION

Critical Infrastructures (CIs) are essential resources for the performance of society, including its economy and its security, understood as safety of citizens and security of society's assets. They are slightly differently defined in different countries. However, there is general agreement that CIs include government, telecommunication based on ICT (information and communication technology); financial sector; energy supply; water supply; transportation systems; health sector; and security services (first responders, police, military).

CIs are interconnected and, hence, interdependent (see e.g., Macaulay, 2008). As consequence, the performance of any CI influences the performance of other CIs and depends on the other CIs performance. The behavior over time of CIs is extremely complex. There are two kinds of complexity: *detail complexity* and *dynamic complexity*. Detail complexity is related to the system size (number of components and functions of each CI). Beyond detail complexity, the system of CIs is *dynamically complex* (Sterman, 2000, p21-23). Dynamic complexity is characterized by a set of criteria, which all are satisfied by any system of CIs. The system's behavior is time-dependent and changing ("dynamic"); the system is tightly coupled and, hence, governed by feedback effects; the relations between the CI components are mostly nonlinear; managerial interventions are typically resource intensive and costly, thus precluding taking other interventions and determining the future course ("path dependence"); the complexity of the interconnected CIs challenges the human ability to understand them, often resulting in counterintuitive system behavior, inviting interventions that fail or even worsen the situation ("policy resistance"); feedback in the system typically shows up time-delayed, which can lead to long-run responses that are very different from the short-run outcomes, to the extent that solutions that work in the short run may become harmful in the long run.

Detail complexity can be overcome by breaking the problem in subproblems that are easier to solve ("divide and conquer"). The dynamic complexity of systems cannot be mastered by breaking the system in smaller systems, since the complexity arises through the interconnections and interdependencies across any imagined boundary

between subsystems.

In the event of a disruption occurring in some CI, the interdependencies among CIs pave the way for secondary disruptions in other CIs, called cascading effects (Franchina, Carbonelli, Gratta, Crisci and Perucchini, 2011) or cascading failures (Katina and Keating, 2015). The literature has identified several types of interdependencies (see ref. Ouyang, 2014, Table 1 and examples E1-E10, on p45-46)

Owing to the extreme complexity of the CI system, many different approaches, targeting different purposes, exist for analyzing cascading effects. No single approach does full justice to the problem's complexity. To the best of our knowledge, the most recent extensive review of modeling and simulation of interdependent CIs was performed by Ouyang (2014). A useful model is designed for a purpose, viz. answering specific questions, hence the model simplifies the description of reality to preserve what is relevant for the model's purpose, excluding what is irrelevant. Ouyang's review covers six modeling categories for different purposes, viz. empirical approaches, agent-based approaches, system dynamics-based approaches, economic theory-based approaches, network-based approaches, and miscellaneous modeling approaches.

One modeling category is not included among Ouyang's review, viz., desktop-based expert assessment of CI interdependencies and cascading failures, most certainly because peer-reviewed publications of such activities are missing. A desktop exercise (a.k.a. tabletop exercise) is conducted with participants sitting around a table, addressing a fictional scenario. Desktop exercises concerning risk assessment in CIs are also model-based, since they are synthesis of the mental models of practitioners representing each of the CIs as well as the mental models of people with cross-cutting expertise on CIs. The distance from the synthesized mental model for risk assessment to conducting a simulation (i.e., figuring out the consequences of the model) is short. It is in principle possible to extend the modeling exercise to figure out the consequences. Another, more powerful option, is the one we follow in this paper: using the expert estimates in a system dynamics simulation model.

Desktop-based expert assessment of CI interdependencies and cascading failures are typically performed by organizations having homeland security as mission. Hence, such assessments are important. But then, the research question arises: To what extent can expert practitioner assessments account for the aggregate impact of the cascading failures upon a disruption affecting a critical infrastructure? Indeed, since CIs are interdependent, a disruption affecting a given CI will propagate along multiple feedback loops, causing primary, secondary, tertiary, etc. cascading failures (kind of "ripple effect"). Is this ripple effects moderate, in the sense that it gets quickly damped and the contribution of the primary cascading failures dominate? Or can the aggregate contribution of higher order cascading failures make the ripple effect quite considerable, especially if the duration (or the intensity) of the original disruption is large?

To address the research question, we provide the necessary background information in section "Details of the assessment in the Norwegian desktop exercise"; in section "Expert assessment of cascading failures" we review recent work (Laugé, 2014, Laugé, Hernantes and Sarriegi, 2015) that will allow us develop a quantitative simulation model to answer the research question; in section "System Dynamics model" we explain the key equations of the simulation model and the validation process (the full description of the model is given in the appendix). In section "Assessment of the reliability of expert estimates" we present the simulation results; they provide evidence that expert estimates of cascading failures become less accurate when the length of the disruption triggering the cascading failures increases. In the final section, we provide an interpretation of our findings; in addition, we discuss the robustness of our findings, given the limitations of our study.

DETAILS OF THE ASSESSMENT IN THE NORWEGIAN DESKTOP EXERCISE

In this section, we review the findings of the expert assessment of cascading failures in a risk analysis of a cyber-attack on the Norwegian telecommunication CI sector (DSB, 2015). The corresponding desktop exercise was coordinated by the Norwegian Directorate of Civil Protection (abbreviated DSB, from the initials in the Norwegian name). The risk analysis of a cyber-attack was part of the "National Risk Analysis 2014", considering disasters that may affect the Norwegian society.

Two one-day seminars were conducted. Seminar 1, done in Oslo 12th June 2014, assembled 30 expert participants representing the following CI sectors: energy supply; transportation systems; emergency/security services; water supply; financial sector; health sector; and telecommunication sector. The scenario of seminar 1 was a cyber-attack causing complete disruption lasting 5 days of the ICT CI's transport network in Norway. The leading question posed at seminar 1 was: How will the critical functions in *your own CI sector* be affected by the disruption in the telecommunication sector.

The experts representing a given CI were asked to describe how the disruption in the telecommunication critical infrastructure would impact the performance of their own CI. The detailed answers were afterward mapped to a qualitative scale of values [small, medium, large] for the impact. Thus, the desktop exercise elicited expert

assessments of *primary* cascading failures based on judgmental methods. Note that no quantitative forecasting methods were used, i.e., no time series data were produced. No doubt because of the duration of the event (one day), less effort was dedicated for how the cascading failures further propagated to other CIs and which were the secondary, tertiary, etc. impacts. In fact, the report does not provide qualitative estimates, small/medium/large impact, for propagation of the primary cascading failures to induce secondary cascading failures, and further down to tertiary, quaternary, etc. cascading failures.

Leaving out the detailed description of the cascading failures, the overall assessment was that a cyber-attack causing complete disruption of the ICT CI's transport network for 5 days in Norway would have:

- high impact on the security CI sector;
- high impact on the financial CI sector;
- high impact on railways and airline traffic, and moderate impact on other transport CIs;
- low impact on the water supply CI sector;
- low impact on the energy supply CI sector; but then secondary cascading failures from minor disruptions on energy infrastructure would increase significantly the disruption of ICT CI;
- moderate impact on the health CI sector.

Seminar 2, conducted 1st September 2014, addressed other consequences of the hypothetical cyber-attack (how it would affect citizens; its influence on societal indicators; losses accrued). Seminar 2 is out of scope for our study.

It is not possible to answer our research question with data from the report by the Norwegian Directorate of Civil Protection (DSB, 2015): 1) the expert assessment did not go beyond assessment of the impact of primary cascading failures; and 2) no further and deeper desktop exercise was conducted that would provide a benchmark to determine the degree to which the impact assessments of the experts are off the mark.

Thus, we ask if there are studies providing estimates of cascading failures across all CI sectors? That is, we ask for estimates of cascading failures considering all possible values of *j* and *k*, how a disruption in a sector *j* (CI_j) affects other CI sector *k* (CI_k).

EXPERT ASSESSMENT OF CASCADING FAILURES

Fortunately, a Ph.D. research project conducted by Ana Laugé, with a Ph.D. thesis available electronically (Laugé, 2014) and a journal publication (Laugé, Hernantes and Sarriegi, 2015), provides the data we are looking for.

Laugé conducted a survey with CI managers to obtain estimates on a Likert scale for cascading impacts caused by disruptions of different durations in a CI_j, where the index j, running from 1 to 11, refers to the following CI sectors: Energy supply; ICT; Water supply; Food; Health; Financial; Order & Safety; Civil Administration; Transport; Chemical & Nuclear; and Space & Research, respectively. She obtained estimates for the cascading impacts on CI_k, where the index k run through all values between 1 and 11 (of course, excluding j=k). Laugé asked the experts to provide estimates of direct dependencies between any two CIs in case the disruption period was less than two hours, less than six hours, less than 12 hours, less than 24 hours, more than 24 hours and more than one week. She computed averages of the provided estimates, resulting in tables for each of the cases. As example, see Figure 1, adapted from ref. (Laugé, 2014), p175.

Now, as in the case of the Norwegian desktop exercise, the experts participating in Laugé's survey provided estimates for how much a total disruption in CI sector *j* (CI_j) impacted another CI sector *k* (CI_k). But as opposed to the Norwegian case, where only one value of *j* was considered (viz. the telecommunications Critical Infrastructure), in Laugé's case she obtained an 11x11 matrix describing all possible impacts on other CIs coming from any disrupted CI. Note that the expert estimates tacitly include expert knowledge about response measures in the affected CI sectors. In other words, notwithstanding that the net impact of the cascading failures is an assessment of failures, we must trust that the experts' knowledge included expertise about preparedness, mitigation and response capability in *their home CI*.

Using Laugé's data, it becomes then possible to use a system dynamics model embedding the cascading failures estimates from Laugé's Ph.D. thesis (Laugé, 2014) to compare how reliable the expert estimates are. The trick is to compare two simulation outcomes, viz. the outcome considering the unrestricted propagation of the cascading failures vs the outcome that only accounts for the primary cascading failures.

Effect on / Failed CI	Energy	ICT	Water	Food	Health	Financial	Order & Safety	Civil Admin.	Transport	Chemical & Nuclear	Space & Research
Energy	-	4.1	3.7	4.6	4.6	4.3	5	3	4	5	3
ICT	4.3	-	2.7	4.1	4	4.3	4.3	2.8	4.2	5	2.7
Water	3.2	2.4	-	4	3.4	0.7	3.7	2.8	2	3.7	1.7
Food	2.5	1.6	1	-	3.4	0	3.7	1.2	0.6	1.3	1.7
Health	1.8	1.6	0.7	2.2	-	0.3	4.3	2.8	0.8	1	1.3
Financial	2.7	1.4	1.3	3.1	1.8	-	1.7	0.3	1.4	2	1
Order & Safety	3.2	1.7	1.7	2.9	2.4	4	-	2.8	1.8	1.3	1.3
Civil Admin.	1.8	2.1	0.7	1.8	2.8	1.3	1.3	-	1.8	1.7	1.7
Transport	2.8	2.3	2	4.3	3.2	2.7	3.7	2.6	-	1.7	2
Chemical & Nuclear	2.7	1.6	2.3	1.9	1.6	0	3.3	1.4	0.8	-	0.3
Space & Research	0.8	1.6	0.3	0.4	0	0	0.7	0.6	0.6	0	-

Figure 1. Table showing impacts on a CI if other CIs are down for more than 24 hours © Ana Laugé

SYSTEM DYNAMICS MODEL

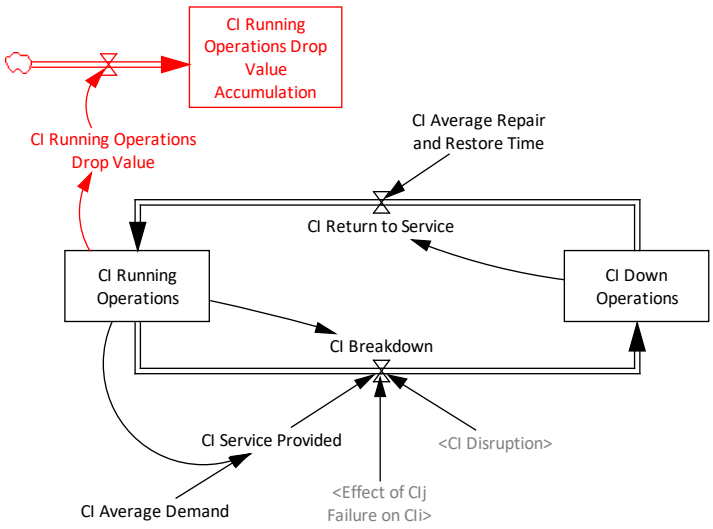


Figure 2: CI System Dynamics Structure (with vector variables – see main text)

The system dynamics model used to produce the results of this research is an extended version of the model published in Abdelgawad, Farstad and Gonzalez (2019), which was inspired by the model built by Canzani (2016). As depicted in Figure 2 (system dynamics structure in black color), in our model every CI has a CI_i *Running Operations* level which contains all this CI's functioning operations divided by its all operations capacity of this CI, i.e. the fraction of the functional operations. A disruption depletes the running operations through the CI_i *Breakdown* rate, and increases the value of the CI_i *Down Operations* level, which contains the non-functional operations fraction of all operations of this CI. A recovery process will restore the operations back to CI_i *Running Operations* through the CI_i *Return to Service* rate. Our model utilized the Vensim DSS subscripts to vectorize the same system dynamics structure/equations to be used for all above mentioned 11 CIs

included in Laugé's research (that is, the index *i* assumes values 1…11, labeling eleven CI sectors).

In the following, we provide a description of the key equations and parameters along with the validation of our model (see also Abdelgawad, Farstad and Gonzalez, 2019, p631-634). In the appendix, we provide a full description of the model, including documentation of parameters and equations.

Both $CI_i\ Running\ Operations$ and $CI_i\ Down\ Operations$ levels are respectively defined as:

$$CI_i\ Running\ Operations = \int_0^t (CI_i\ Retun\ to\ Service\ - CI_i\ Breakdown) \cdot dt + 100 \quad (1)$$

and:

$$CI_i\ Down\ Operations = \int_0^t (CI_i\ Breakdown - CI_i\ Retun\ to\ Service) \cdot dt \quad (2)$$

It should be noted that at the beginning of the simulation ($t = 0$) $CI_i\ Running\ Operations = 100$ while $CI_i\ Down\ Operations = 0$, and this is why 100 was added to the former integration.

Furthermore, $CI_i\ Breakdown$[1] and $CI_i\ Return\ to\ Service$ rates are respectively defined as:

$$CI_i\ Breakdown = CI_i\ Disruption + CI_i\ Running\ Operations \cdot \sum_{j \in J} \left(Effect\ of\ CI_j\ Failure\ on\ CI_i \cdot \frac{1 - CI_i\ Service\ Provided}{|J|} \right) \quad (3)$$

Where $|J|$ represents the cardinality (sum of all elements in a set representing the CIs considered), J is an ordered 11-tuple defined as $J = (Energy, ICT, Water, \cdots, Space\ \&\ Research)$, and:

$$CI_i\ Return\ to\ Service = \frac{CI_i\ Down\ Operations}{CI_i\ Average\ Repair\ and\ Restore\ Time} \quad (4)$$

The $CI_i\ Return\ to\ Service$ rate moves the failed operations accumulated inside $CI_i\ Down\ Operations$ level back to $CI_i\ Running\ Operations$ level over an average period of time that is equal to the average total time required to restore and repair these failed operations.

In the model, the $CI_i\ Service\ Provided$ is defined as a piecewise function:

$$CI_i\ Service\ Provided = \begin{cases} 1, & CI_i\ Running\ Operations \geq CI_i\ Average\ Demand \\ \dfrac{CI_i\ Running\ Operations}{CI_i\ Average\ Demand}, & CI_i\ Running\ Operations < CI_i\ Average\ Demand \end{cases} \quad (5)$$

he $CI_i\ Average\ Demand$ was arbitrarily assumed to be 95% of this CI's full capacity required to supply the demand of its dependent CIs.

Laugé's research presented the effects of all failed CIs on all other CI in different tables. Each of these tables represents a different disruption duration, which means that the effect of certain failed CI on another CI changes over time as far as the failure continues. The successive effects of one failed CI on another were extracted from Laugé's tables and were pushed in a separate vector for each pair of CIs using time (disruption durations) as its index. Figure 3 shows Laugé's successive tables as well as marking the effects for the ICT Energy pair. These vectors of each pair of CIs were included in the model as time-based graphical functions to account for these over-time changes or dynamics. These graphical functions were included in the model through $Effect\ of\ CI_j\ Failure\ on\ CI_i\ Data$. The graphical function of the effect of CI_2 failure on the CI_1 is shown in Figure 4 as an example (i=1 denotes Energy, while j=2 denotes ICT).

[1] In the model, a more complex equation for $CI_i\ Breakdown$ was used for technical reasons. However, the simplified version showed in the paper will act similarly in general.

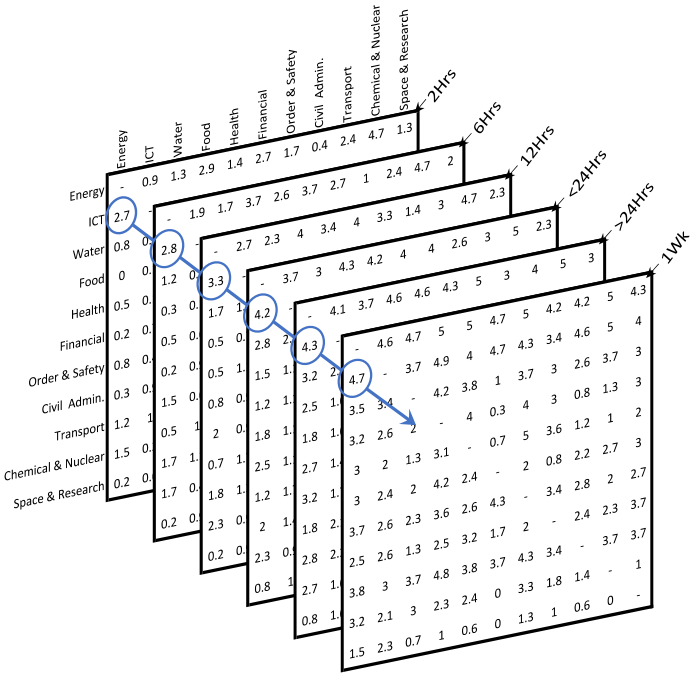


Figure 3. CI Interdependencies for Different Durations (Abdelgawad, Farstad and Gonzalez, 2019)

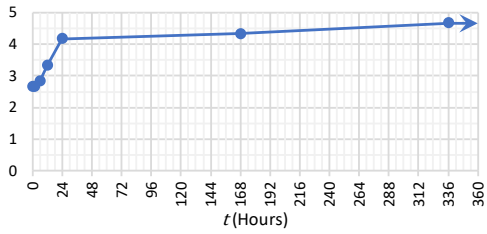


Figure 4. Effect of CI_2 Failure on CI_1 over Time (Disruption Durations) [i=1 denotes Energy, while j=2 denotes ICT] (Abdelgawad, Farstad and Gonzalez, 2019)

In the model, a disruption occurring to any of the CIs is produced in the CI Disruption structure shown in Figure 6 (structure in black color). The $CI_i\ Disruption$ is defined as:

$$CI_i\ Disruption = CI_i\ Disruption\ Magnitude \cdot \Pi_{t_d,(t_d+\Delta T)}(t) \quad (6)$$

$\Pi_{t_d,(t_d+\Delta T)}(t)$ is a Boxcar function (Weisstein), where: t denotes the time or the simulation time in the case of the model, t_d denotes the beginning of the disruption or the $CI_i\ Disruption\ Time$ in the model, and ΔT denotes the $CI_i\ Disruption\ Duration$. In piecewise notation, $\Pi_{t_d,(t_d+\Delta T)}(t)$ can be defined as (Figure 5 shows its graphical representation):

$$\Pi_{t_d,(t_d+\Delta T)}(t) = \begin{cases} 0, & t < t_d \\ 1, & t_d \le t < (t_d + \Delta T) \\ 0, & t \ge (t_d + \Delta T) \end{cases}$$

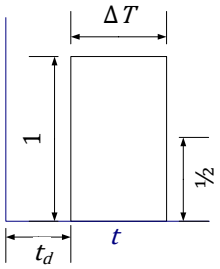


Figure 5. Boxcar function graph

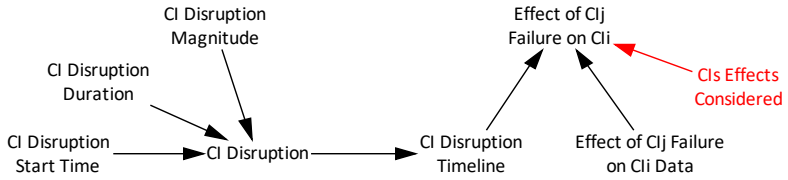


Figure 6. CI Disruption Structure

The beginning of a disruption through $CI_i\ Disruption$ triggers the above mentioned time-based graphical functions that account for the dynamics recognized via Laugé's interdependencies tables. In the model, the beginning of a disruption starts a new timeline different from the simulation timeline. This new timeline (generated inside $CI_i\ Disruption\ Timeline$) continues as long as the disruption remains and stops otherwise. Figure 7 shows the original timeline of the model (i.e. simulation time) and another disruption timeline for a CI disruption that

starts at hour 48 and ends 24 hours later.

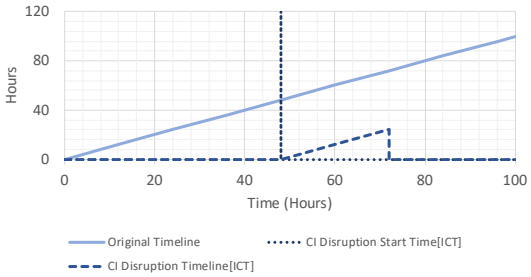


Figure 7. Generated Disruption Timeline

MODEL TESTING AND VALIDATION

To detect any issues in our model as well as increase trust in our model, we have used all the applicable tests introduced by Forrester and Senge (1996) and recommended by Sterman (2000). Our model inherited the same boundaries and basic structure of Canzani's model (Canzani, 2016), which although a simple model, includes all necessary components to study a CI disruption effect at this level of aggregation, making it possible for the model to pass the boundary adequacy test (Sterman, 2000, Forrester and Senge, 1996, Barlas, 1996) After including the fixes introduced in Abdelgawad, Farstad and Gonzalez (2019), the model is more consistent with the relevant descriptive knowledge of the system enabling it to pass the structure assessment (Sterman, 2000, Barlas, 1996).

Other than a few arbitrarily chosen values which were included in the model, all other parameters were retrieved from Laugé's survey. Accordingly, the parameters are consistent with relevant descriptive and numerical knowledge of the system (Sterman, 2000, Forrester and Senge, 1996, Barlas, 1996). Unit check of Vensim DSS (Ventana Systems, 2009) assured the model dimensional consistency (Sterman, 2000, Forrester and Senge, 1996, Barlas, 1996). Moreover, the model was tested for integration errors (Sterman, 2000), and the combination of Euler's method and time step of 0.125 was found suitable.

The model's robustness has been tested with successful results under extreme conditions (Sterman, 2000, Forrester and Senge, 1996, Barlas, 1996). To further test the model's robustness under assumed uncertainties in parameters and initial values, sensitivity analysis (Sterman, 2000, Forrester and Senge, 1996) was applied to the model using. There is no information about the probability distribution of the parameters, accordingly, we have assumed Uniform probability distribution for all parameters. We did not have any benchmark for the numerical changes in the model variables due to the change in any of the tested parameters to test our results against. However, in all sensitivity tests we have conducted, we have not spotted any change in the modes of behavior, consequently, no policy implications change due to the change in the values of the parameters. Therefore, the results were found acceptable.

ASSESSMENT OF THE RELIABILITY OF EXPERT ESTIMATES

To find the difference between the case in which the cascading failures among the CIs are taken into consideration and in which they are not, we have made some changes to the system dynamics model used in Abdelgawad, Farstad and Gonzalez (2019). The first change was adding a new variable $CI_j\ Effect\ Considered$, shown in Figure 6 (in red color). This variable is an eleven elements binary vector. Every element corresponds to a CI sector, CI_i. This vector controls which CI interdependencies to be taken into consideration during the simulation, i.e. it controls which elements of $Effect\ of\ CI_j\ Failure\ on\ CI_i\ Data$ that would be included in $Effect\ of\ CI_j\ Failure\ on\ CI_i$.

For example, in the case of considering only the direct effects caused by the failure of ICT CI on all other CIs, and not considering the propagated cascading failures of all other CIs, elements of the vector $CI_i\ Effect\ Considered$ would be all zeros except the second element (denotes the ICT CI) which would be one. i.e. $CI_j\ Effect\ Considered = [0 \quad 1 \quad 0 \quad \cdots \quad 1]$. In such a case, the value of $Effect\ of\ CI_j\ Failure\ on\ CI_i$ would be expressed as follows:

$$Effect\ of\ CI_1\ Failure\ on\ CI_i = 0 \cdot Effect\ of\ CI_1\ Failure\ on\ CI_i\ Data$$

$$Effect\ of\ CI_2\ Failure\ on\ CI_i = 1 \cdot Effect\ of\ CI_2\ Failure\ on\ CI_i\ Data$$

$$Effect\ of\ CI_3\ Failure\ on\ CI_i = 0 \cdot Effect\ of\ CI_3\ Failure\ on\ CI_i\ Data$$

$$\vdots$$

$$Effect\ of\ CI_{11}\ Failure\ on\ CI_i = 0 \cdot Effect\ of\ CI_{11}\ Failure\ on\ CI_i\ Data$$

In matrix form:

$$Effect\ of\ CI_j\ Failure\ on\ CI_i = [0 \quad 1 \quad 0 \quad \cdots \quad 1] \cdot Effect\ of\ CI_j\ Failure\ on\ CI_i\ Data$$

In this equation, only direct effects of a failed ICT CI on all other CIs are taken into consideration, however, the cascading failures from the affected CIs will not be propagated. On the other hand, in the normal case in which all cascading failures are considered, elements of the vector $CI_j\ Effect\ Considered$ will be all ones. Accordingly, the $Effect\ of\ CI_j\ Failure\ on\ CI_i$ would be:

$$Effect\ of\ CI_j\ Failure\ on\ CI_i = [1 \quad 1 \quad \cdots \quad 1] \cdot Effect\ of\ CI_j\ Failure\ on\ CI_i\ Data$$

Using this new vector $CI_j\ Effect\ Considered$, we were able to simulate the model with the higher order cascading failures OFF and ON. To clarify the difference between the two cases, we will present the detailed results of two different simulation cases, one that excludes the higher order cascading failures (denoted by: cascading OFF) and another that includes the cascading failures (cascading ON). In both cases the model was injected with a disruption in the ICT CI that started after 48 hours from the beginning of the simulation with the a magnitude of ten (which is the highest disruption magnitude defined by Canzani (2016)), and ended after 24 hours. The left graph in Figure 8 shows the Running Operations behavior over time for all CIs in case the higher order cascading failures are not included, while the right graph shows the same Running Operations in case that all the cascading failures are included.

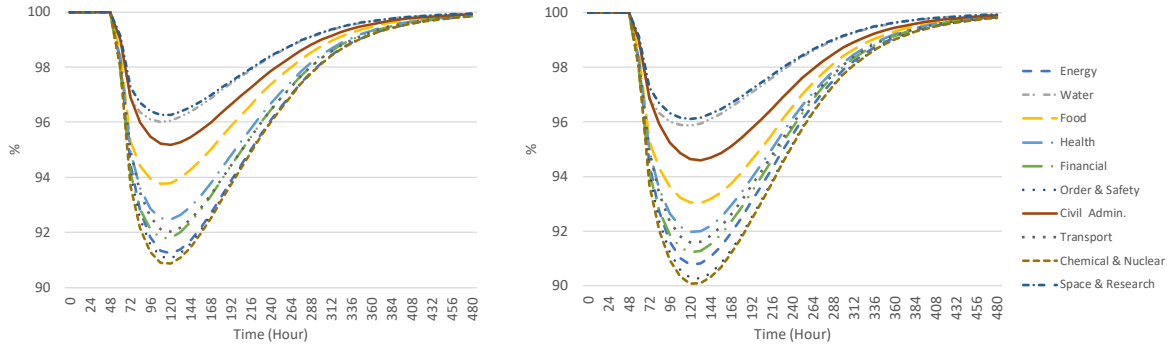


Figure 8. Running Operations (Left: Cascading OFF | Right: Cascading ON)

Figure 9 shows the Service Provided by all CIs in both simulations mentioned above, higher order cascading failures are not included in the left graph, while included in the right graph.

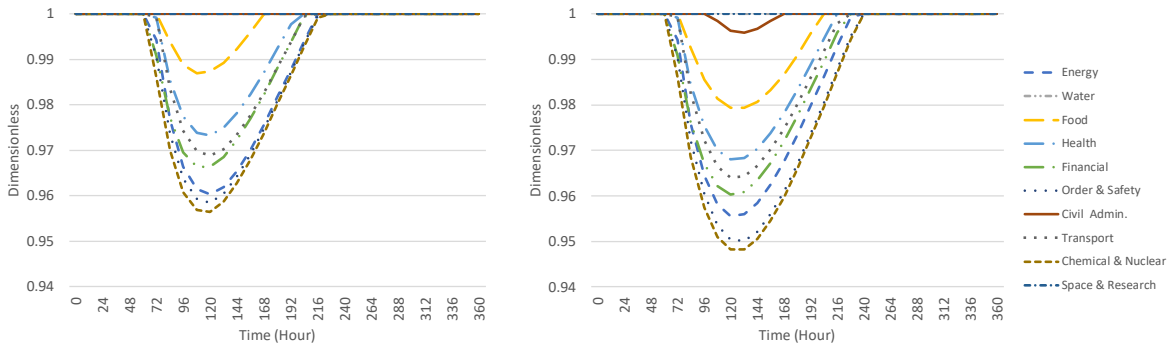


Figure 9. Services Provided (Left: Cascading OFF | Right: Cascading ON)

Differences between the two simulation cases can be visually identified through Figure 8 and Figure 9. Nonetheless, to quantitively assess the difference between them, our second addition to the model (shown in red color in Figure 2) calculates $CI_i\ Running\ Operations\ Drop\ Value$, which is defined as:

$$CI_i\ Running\ Operations\ Drop\ Value = 100 - CI_i\ Running\ Operations$$

Then the new structure calculates the area under the curve of $CI_i\ Running\ Operations\ Drop\ Value$ as well. The area under the curve is the accumulation or the integration of the $CI_i\ Running\ Operations\ Drop\ Value$ over

time, i.e.:

$$CI_i\ Running\ Operations\ Drop\ Value\ Accumulation = \int_0^t CI_i\ Running\ Operations\ Drop\ Value \cdot dt$$

At the beginning of the simulation $CI_i\ Running\ Operations\ Drop\ Value\ Accumulation = 0$ by design. Figure 10 shows the $CI_i\ Running\ Operations\ Drop\ Value\ Accummulation$ of all CIs in both cases, cascading failure are excluded in the left graph, and included in the right graph.

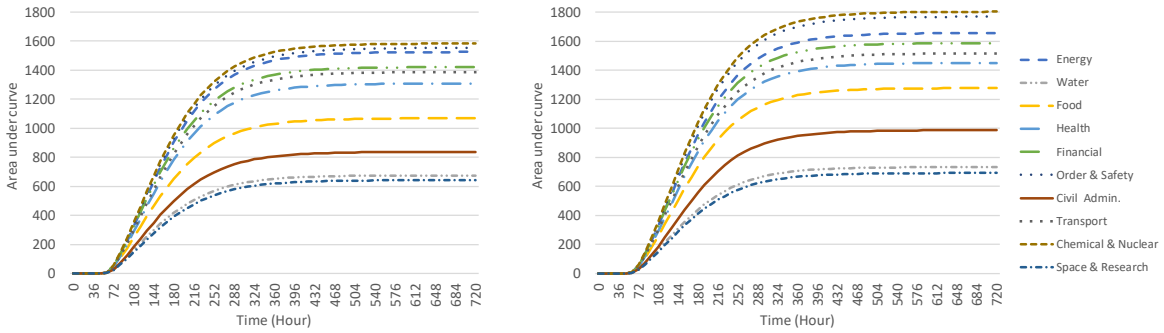


Figure 10. Area under the Curve (Left: Cascading OFF | Right: Cascading ON)

To compare the difference between the two areas under the curve per CI of both cascading ON and OFF simulations, we used the following equation:

$$\Delta = \frac{Area\ under\ Curve_{Cascading\ ON} - Area\ under\ Curve_{Cascading\ OFF}}{Area\ under\ Curve_{Cascading\ OFF}}$$

For a more comprehensive set of results, we have conducted another five experiments. In each experiment, we have changed the disruption period and kept everything else as it was. The disruption periods we have used matched Laugé disruption durations, i.e. two hours, six hours, 12 hours, 24 hours, 168 hours, and 336 hours. Table 1 shows the identified differences Δ per CI as resulted from these different ICT CI disruption durations. Figure 11 shows the same results in a graph.

Table 1. The Identified Differences Δ Resulted from Different ICT CI Disruption Durations as Defined by Laugé

ICT CI Disruption Duration / Δ per CI	2 Hours	6 Hours	12 Hours	24 Hours	168 Hours	336 Hours
Energy	0 %	0 %	4.37 %	8.62 %	23.47 %	23.69 %
Water	0 %	0 %	5.01 %	8.39 %	15.72 %	13.72 %
Food	0 %	0 %	10.49 %	19.43 %	42.73 %	39.55 %
Health	0 %	0 %	5.38 %	10.86 %	31.03 %	32.31 %
Financial	0 %	0 %	6.38 %	11.69 %	27.03 %	26.25 %
Order & Safety	0 %	0 %	6.82 %	13.87 %	39.06 %	40.62 %
Civil Admin.	0 %	0 %	9 %	17.78 %	43.74 %	40.22 %
Transport	0 %	0 %	4.90 %	9.33 %	23.13 %	22.08 %
Chemical & Nuclear	0 %	0 %	7.33 %	13.91 %	34.37 %	34.38 %
Space & Research	0 %	0 %	4.05 %	7.55 %	18.46 %	15.91 %

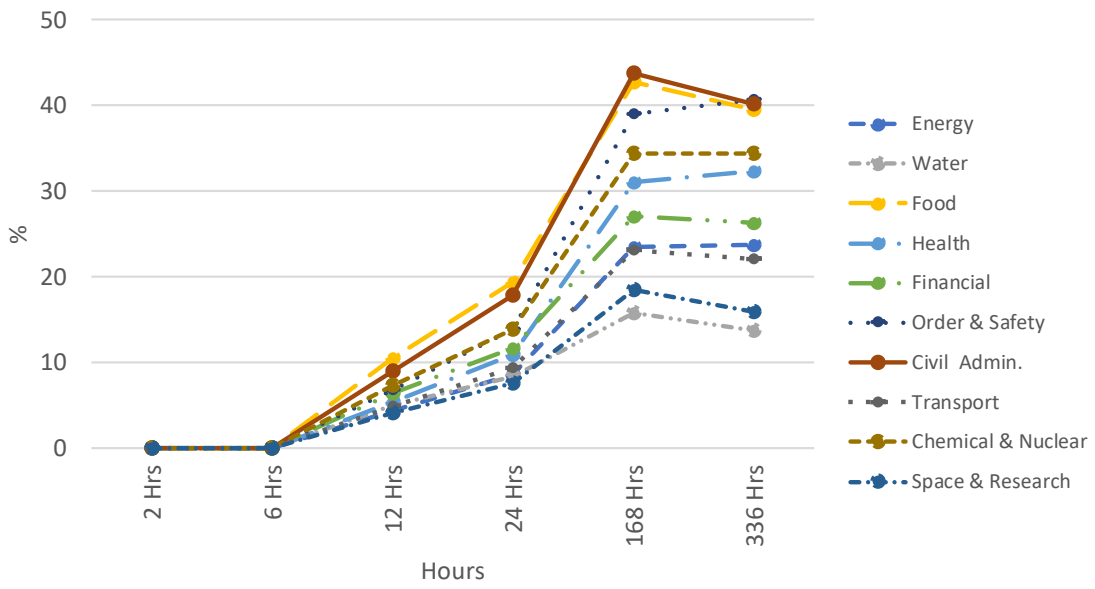


Figure 11. Behavior of the Identified Differences Δ Resulted from Different ICT CI Disruption Durations as Defined by Laugé

CONCLUSION

Desktop simulation exercises have been often employed to engage first-responders in relevant scenarios related to emergency management, with emergency understood as generic term for crisis and disaster situations (Smith, Dowel and Ortega-Lafuente, 1999). Most often, the purpose of emergency management desktop exercises is to train the different role-players in situations where they would have to act together. The literature distinguishes between two main categories of desktop simulation exercises: scenario planning and scenario-based planning (Van Niekerk, Coetzee, Botha, Murphree Michael, Fourie, Le Roux, Wentink, Kruger, Shoroma, Genade, Meyer and Annandale, 2014).

Our point of departure was a desktop modeling exercise targeting expert assessment of *primary* cascading failures, specifically, the immediate consequences upon other CI sectors triggered by a disruption in the telecommunication CI sector (the disruption being a complete breakdown of five days duration of the telecommunication CI sector owing to a sophisticated cyber-attack). We asked the questions: 1) Is the aggregate impact of the cascading failures moderate, in the sense that this "ripple effect" is quickly damped and the contribution of the primary cascading failures dominate? Or can the aggregate contribution of higher order cascading failures make the ripple effect quite considerable, especially for large values of the duration (or the intensity) of the original disruption?

To answer the question, we developed a system dynamics simulation model using estimates of primary cascading effects obtained by Laugé (Laugé, 2014, Laugé, Hernantes and Sarriegi, 2015). The simulation results show, indeed, that the ripple effect becomes more and more significant the longer the duration of the original disruption.

For an explanation, we point the reader's attention to the richness of feedback loops in a CI system. The system dynamics model in Figure 2, describing a system of 11 interdependent CI sectors has a huge number of feedback loops (a total of 308,152 loops, in fact). The "simplicity" of the model structure is deceptive, because the choice of vector variables that makes the model diagram compact hides the pathways of propagation of cascading failures along the model's feedback loops.

Owing to the huge number of feedback loops, the original disruption finds many pathways to propagate to other CI sectors and cause failures (primary cascading failures). In turn, the primary cascading failures can propagate along the many pathways to cause secondary cascading failures, etc. Intuitively, one expects damping of the failures, the higher the order of the cascading failures is. Intuitively also, one expects that the damping effect becomes less and less pronounced the longer the duration of the original disruption is. Accordingly, our simulation results should not be surprising.

Surprising results or not, our research question needed to be posed and addressed. Ultimately, the question relates to the human ability to intuitively deal with complexity. Here, the issue is the ability of human minds, even if they are expert ones, to intuitively assess the contribution of a huge number of pathways to the ripple effect. In the

light of our results, since the desktop assessment (DSB, 2015) concerned a total disruption of the telecommunication CI sector of five days duration some doubts arise as to the ability of the experts to account for the aggregate effects of cascading failures in the scenario. It is hard to expect that the experts' assessment is anchored in mental aggregation and computation of cascading failures up to higher orders.

How robust are our results? We admit that the data set from Laugé refers to assessment of cascading failures in Spanish Critical Infrastructure while our research question emerged in the context of Norwegian Critical Infrastructure. Hence, we cannot claim that the quantitative results of our simulation must be accurate renderings of the situation in Norway (or for that matter in other countries). Also, we have restricted our simulation to a plausible set of parameters for repair and restores times. But we would expect the validity of the qualitative finding of more significant ripple effect, the longer the duration of the original disruption.

Owing to the practical relevance of assessment of cascading failures and the fact that here the interests of practitioners and researchers meet, we hope to trigger the interest of these communities to elicit and test relevant data.

Once our results are confirmed by other researchers and with more solid data, we believe that the proposed system dynamics model could be a valuable addition to desktop exercises. Its diagram structure (Figure 2) is quite compact and, in a sense, simple and intuitive. Its worth for practitioners would be anchored in the model's ability to extend human assessment of primary cascading failures to include higher order cascading failures (i.e., the totality of the ripple effect).

REFERENCES

[1] Macaulay, T. (2008). *Critical Infrastructure: Understanding Its Component Parts, Vulnerabilities, Operating Risks, and Interdependencies*, CRC Press, Boca Raton, FL, USA.
[2] Sterman, J. D. (2000). *Business Dynamics : Systems Thinking and Modeling for a Complex World*, Irwin/McGraw-Hill, Boston.
[3] Franchina, L., Carbonelli, M., Gratta, L., Crisci, M., and Perucchini, D. (2011). "An impact-based approach for the analysis of cascading effects in critical infrastructures." *International Journal of Critical Infrastructures*, 7(1), 73-90.
[4] Katina, P., and Keating, C. (2015). "Critical infrastructures: A perspective from systems of systems." *International Journal of Critical Infrastructures*, 11(4), 316-344.
[5] Ouyang, M. (2014). "Review on modeling and simulation of interdependent critical infrastructure systems." *Reliability Engineering & System Safety*(121), 43-60.
[6] Laugé, A. (2014). " Crisis Management Toolbox: the Relevant Role of Critical Infrastructures and their Dependencies"." PhD thesis, Universidad de Navarra, San Sebastian, Spain.
[7] Laugé, A., Hernantes, J., and Sarriegi, J. M. (2015). "Critical infrastructure dependencies: A holistic, dynamic and quantitative approach." *International Journal of Critical Infrastructure Protection*, 8, 16-23.
[8] DSB (2015). "Risikoanalyse av «Cyberangrep mot ekom-infrastruktur»." Norwegian Directorate for Civil Protection (DSB).
[9] Abdelgawad, A. A., Farstad, T.-E., and Gonzalez, J. J. (2019). "Vulnerability Analysis of Interdependent Critical Infrastructures upon a Cyber-attack." *Proceedings of the 52nd Hawaii International Conference on System Sciences*, T. Bui, ed., University of Hawai'i at Manoa, Maui. Hawai'i, USA, 629-638.
[10] Canzani, E. (2016). "Modeling Dynamics of Disruptive Events for Impact Analysis in Networked Critical Infrastructures." *Proceedings of ISCRAM2016*, A. Tapia, P. Antunes, V. A. Bañuls, K. Moore, and J. Porto, eds., Federal University of Rio de Janeiro.
[11] Weisstein, E. W. "Boxcar Function." *MathWorld--A Wolfram Web Resource*.
[12] Forrester, J. W., and Senge, P. M. (1996). "Tests for Building Confidence in System Dynamics Models." *Modelling for Management: Simulation in Support of Systems Thinking*, G. P. Richardson, ed., Dartmouth Publishing Group.
[13] Canzani, E. "Modeling Dynamics of Disruptive Events for Impact Analysis in Networked Critical Infrastructures." Federal University of Rio de Janeiro, Rio de Janeiro, Brasil.
[14] Barlas, Y. (1996). "Formal Aspects of Model Validity and Validation in System Dynamics." *System Dynamics Review*, 12(3), 183-210.
[15] Ventana Systems (2009). "Vensim DSS." Ventana Systems, Inc., Harvard, MA, USA.
[16] Smith, W., Dowel, J., and Ortega-Lafuente, M. A. (1999). "Designing Paper Disasters: An Authoring Environment for Developing Training Exercises in Integrated Emergency Management." *Cognition, Technology & Work*, 1, 119-131.
[17] Van Niekerk, D., Coetzee, C., Botha, D., Murphree Michael, J., Fourie, K., Le Roux, T., Wentink, G., Kruger, L., Shoroma, L., Genade, K., Meyer, S., and Annandale, E. (2014). "Planning and Executing Scenario Based Simulation Exercises: Methodological Lessons." *jhsem*, 12(1), 193-207.

[18] Argonne National Laboratory (2014). "SDM-DOC/.NET." The Global Security Sciences Division at Argonne National Laboratory, Argonne, IL.
[19] Martinez-Moyano, I. J. (2012). "Documentation for Model Transparency." *System Dynamics Review*, 28(2), 199-208.

APPENDIX

In this appendix, we present a full description of our model. The description was generated based on the model's Vensim file using SDM-DOC (the .NET version) (Argonne National Laboratory, 2014), described in (Martinez-Moyano, 2012). Some manual editing and cleaning were conducted. The following table contains the variables' counts, symbols, types, and abbreviations used in the description below.

L: Level (6/**66**) *	**F**: Flow (6)	**A**: Auxiliary (17)	**C**: Constant (18)	**T**: Lookup (1/**11**) **	**D**: Data (1)	**Sub**: Subscripts (2)

* (state variables/total stocks).

** (lookup variables/lookup tables).

Type	Variable Name and Description
#1 C	**CI Average Demand** (Dimensionless) CI Average Demand [CIi] = 95 **Description:** *An assumption is made that all CI perform on average at 95 percent of full capacity at any given time to supply their demand to each other.* **Present in 1 view:** • All CIs **Used by:** • CI Service Provided
#2 C	**CI Average Demand ICT** (Dimensionless) CI Average Demand ICT [CIi] = 95 **Description:** *Like* **CI Average Demand**. **Present in 1 view:** • Only ICT **Used by:** • CI Service Provided ICT
#3 C	**CI Average Repair and Restore Time** (Hours) CI Average Repair and Restore Time [CIi] = 72 **Description:** *The sum of the total average repair and restore time variables from Canzani's model.* **Present in 1 view:** • All CIs **Used by:** • CI Return to Service
#4 C	**CI Average Repair and Restore Time ICT** (Hours) CI Average Repair and Restore Time ICT [CIi] = 72 **Description:** *Like* **CI Average Repair and Restore Time**. **Present in 1 view:** • Only ICT **Used by:** • CI Return to Service ICT
#5 F,A	**CI Breakdown** (Dimensionless/Hour) CI Breakdown [CIi] = MIN (CI Running Operations[CIi]/ Fastest Draining Time ,CI Disruption[CIi]+ Unit Normalization* CI Running Operations[CIi] / 100 * ZIDZ (((Effect of CIj Failure on CIi[CIi,Energy] * (1 - CI Service Provided[Energy])) + (Effect of CIj Failure on CIi[CIi,ICT] * (1 - CI Service Provided[ICT])) + (Effect of CIj Failure on CIi[CIi,Water] * (1 - CI Service Provided[Water])) + (Effect of CIj Failure on CIi[CIi,Food] * (1 - CI Service

Type	Variable Name and Description
	Provided[Food])) + (Effect of CIj Failure on CIi[CIi,Health] * (1 - CI Service Provided[Health])) + (Effect of CIj Failure on CIi[CIi,Financial] * (1 - CI Service Provided[Financial])) + (Effect of CIj Failure on CIi[CIi,Public and legal order and safety] * (1 - CI Service Provided[Public and legal order and safety])) + (Effect of CIj Failure on CIi[CIi,Civil administration] * (1 - CI Service Provided[Civil administration])) + (Effect of CIj Failure on CIi[CIi,Transport] * (1 - CI Service Provided[Transport])) + (Effect of CIj Failure on CIi[CIi,Chemical and nuclear industry] * (1 - CI Service Provided[Chemical and nuclear industry])) + (Effect of CIj Failure on CIi[CIi,Space and research] * (1 - CI Service Provided[Space and research]))) , Max Effect of CIj Failure on CIi)) **Description:** *The breakdown rate from running operations to down operations with and added specific disruption, to simulate multiple disruption-scenarios. The rate emulates cascading effects from the other CI's. The If then else clause prevents the level from reaching a negative value. The equation uses the respective e(ij) values from the subscript array.* **Present in 1 view:** • All CIs **Used by:** • CI Down Operations • CI Running Operations
#6 F,A	**CI Breakdown ICT** (Dimensionless/Hour) CI Breakdown ICT [CIi] = MIN (CI Running Operations ICT[CIi]/ Fastest Draining Time ICT ,CI Disruption[CIi]+ Unit Normalization* CI Running Operations ICT[CIi] / 100 * ZIDZ (((Effect of CIj Failure on CIi ICT[CIi,Energy] * (1 - CI Service Provided ICT[Energy])) + (Effect of CIj Failure on CIi ICT[CIi,ICT] * (1 - CI Service Provided ICT[ICT])) + (Effect of CIj Failure on CIi ICT[CIi,Water] * (1 - CI Service Provided ICT[Water])) + (Effect of CIj Failure on CIi ICT[CIi,Food] * (1 - CI Service Provided ICT[Food])) + (Effect of CIj Failure on CIi ICT[CIi,Health] * (1 - CI Service Provided ICT[Health])) + (Effect of CIj Failure on CIi ICT[CIi,Financial] * (1 - CI Service Provided ICT[Financial])) + (Effect of CIj Failure on CIi ICT[CIi,Public and legal order and safety] * (1 - CI Service Provided ICT[Public and legal order and safety])) + (Effect of CIj Failure on CIi ICT[CIi,Civil administration] * (1 - CI Service Provided ICT[Civil administration])) + (Effect of CIj Failure on CIi ICT[CIi,Transport] * (1 - CI Service Provided ICT[Transport])) + (Effect of CIj Failure on CIi ICT[CIi,Chemical and nuclear industry] * (1 - CI Service Provided ICT[Chemical and nuclear industry])) + (Effect of CIj Failure on CIi ICT[CIi,Space and research] * (1 - CI Service Provided ICT[Space and research]))) , Max Effect of CIj Failure on CIi ICT)) **Description:** *Like* **CI Breakdown**. **Present in 1 view:** • Only ICT **Used by:** • CI Down Operations ICT • CI Running Operations ICT
#7 A	**CI Disruption** (Dimensionless/Hour) CI Disruption [CIi] = PULSE TRAIN (CI Disruption Start Time[CIi] ,CI Disruption Duration[CIi] ,Time between CI Disruption Durations[CIi] ,CI Disruption Durations Final Time[CIi])* CI Disruption Magnitude[CIi] **Description:** *The disruptive function d(t), implemented by using the PULSE function to simulate disruptive behaviour at a point in time t with a duration T, multiplied by the Disruption magnitude.* **Present in 2 views:** • All CIs • Only ICT **Used by:** • CI Breakdown • CI Breakdown ICT • CI Disruption Timeline • CI Disruption Timeline Trigger • Delayed CI Disruption
#8 C	**CI Disruption Duration** (Hours) CI Disruption Duration [CIi] = 0, 336, 0, 0, 0, 0, 0, 0, 0, 0, 0

Type	Variable Name and Description
	Description: *The duration of the disruption.* **Present in 1 view:** • All CIs **Used by:** • CI Disruption
#9 C	**CI Disruption Durations Final Time** (Hours) CI Disruption Durations Final Time [CIi] = 720, 720, 720, 720, 720, 720, 720, 720, 720, 720, 720 **Description:** *to limit the number of disruptions, this ends the disruption train.* **Present in 1 view:** • All CIs **Used by:** • CI Disruption
#10 C	**CI Disruption Magnitude** (Dimensionless/Hour) CI Disruption Magnitude [CIi] = 0, 10, 0, 0, 0, 0, 0, 0, 0, 0, 0 **Description:** *The dimensionless magnitude of the disruption, ranging from 0 (no disruption), to 10 (complete breakdown).* **Present in 1 view:** • All CIs **Used by:** • CI Disruption
#11 C	**CI Disruption Start Time** (Hours) CI Disruption Start Time [CIi] = 0, 48, 0, 0, 0, 0, 0, 0, 0, 0, 0 **Description:** *The time during the simulation in which the disruption occurs.* **Present in 1 view:** • All CIs **Used by:** • CI Disruption
#12 A	**CI Disruption Timeline** (Hours) CI Disruption Timeline [CIi] = IF THEN ELSE (CI Disruption[CIi]> 0,Time- CI Disruption Timeline Trigger[CIi] ,0) **Present in 2 views:** • All CIs • Only ICT **Used by:** • Effect of CIj Failure on CIi • Effect of CIj Failure on CIi ICT
#13 A	**CI Disruption Timeline Trigger** (Hours) CI Disruption Timeline Trigger [CIi] = SAMPLE IF TRUE((CI Disruption[CIi]- Delayed CI Disruption[CIi])<> 0,Time ,0) **Present in 1 view:** • All CIs **Used by:** • CI Disruption Timeline
#14 L	**CI Down Operations** (Dimensionless) CI Down Operations [CIi] = $\int$ CI Breakdown[CIi]- CI Return to Service[CIi] *dt* + [0] **Description:** *The down-phase, where the Energy CI has a lack of output in production. Dependent on the rate, disruption and cascading factors.The assumption is made that at t=0 the level is empty.* **Present in 1 view:** • All CIs **Used by:** • CI Return to Service
#15	**CI Down Operations ICT** (Dimensionless)

Type	Variable Name and Description
L	CI Down Operations ICT [CIi] = $\int$ CI Breakdown ICT[CIi]- CI Return to Service ICT[CIi] *dt* + [0] **Description:** *Like* **CI Down Operations**. **Present in 1 view:** • Only ICT **Used by:** • CI Return to Service ICT
#16 F,A	**CI Return to Service** (Dimensionless/Hour) CI Return to Service [CIi] = CI Down Operations[CIi]/ CI Average Repair and Restore Time[CIi] **Description:** *The rate at which the Energy CI returns to full service.* **Present in 1 view:** • All CIs **Used by:** • CI Down Operations • CI Running Operations
#17 F,A	**CI Return to Service ICT** (Dimensionless/Hour) CI Return to Service ICT [CIi] = CI Down Operations ICT[CIi]/ CI Average Repair and Restore Time ICT[CIi] **Description:** *Like* **CI Return to Service**. **Present in 1 view:** • Only ICT **Used by:** • CI Down Operations ICT • CI Running Operations ICT
#18 L	**CI Running Operations** (Dimensionless) CI Running Operations [CIi] = $\int$ CI Return to Service[CIi]- CI Breakdown[CIi] *dt* + [100] **Description:** *Running operations represents the day-to-day functions of the Energy CI. It is assumed that the CI operates at 100% capacity at time t=0.* **Present in 1 view:** • All CIs **Used by:** • CI Breakdown • CI Running Operations Drop Value • CI Service Provided
#19 F,A	**CI Running Operations Drop Value** (Dimensionless) CI Running Operations Drop Value [CIi] = 100-CI Running Operations[CIi] **Present in 1 view:** • All CIs **Used by:** • CI Running Operations Drop Value Accumulation
#20 L	**CI Running Operations Drop Value Accumulation Area under Curve ICT** (Hours) CI Running Operations Drop Value Accumulation Area under Curve ICT [CIi] = $\int$ CI Running Operations Drop Value ICT[CIi] *dt* + [0] **Present in 2 views:** • All CIs • Only ICT **Used by:** • Comparison Results
#21 L	**CI Running Operations Drop Value Accumulation** (Hours)

Type	Variable Name and Description
	CI Running Operations Drop Value Accumulation [CIi] = $\int$ CI Running Operations Drop Value[CIi] *dt* + [0] **Present in 1 view:** • All CIs **Used by:** • Comparison Results
#22 F,A	**CI Running Operations Drop Value ICT** (Dimensionless) CI Running Operations Drop Value ICT [CIi] = 100-CI Running Operations ICT[CIi] **Present in 1 view:** • Only ICT **Used by:** • CI Running Operations Drop Value Accumulation Area under Curve ICT
#23 L	**CI Running Operations ICT** (Dimensionless) CI Running Operations ICT [CIi] = $\int$ CI Return to Service ICT[CIi]- CI Breakdown ICT[CIi] *dt* + [100] **Description:** *Like* **CI Running Operations**. **Present in 1 view:** • Only ICT **Used by:** • CI Breakdown ICT • CI Running Operations Drop Value ICT • CI Service Provided ICT
#24 A	**CI Service Provided** (Dimensionless) CI Service Provided [CIi] = IF THEN ELSE (CI Running Operations[CIi]>= CI Average Demand[CIi] ,1,CI Running Operations[CIi]/ CI Average Demand[CIi]) **Description:** *The control variable which assesses over time the service provided by the Energy CI. Measured between 0 and 1. 0 Being no service provided and 1 representing full service provided.* **Present in 1 view:** • All CIs **Used by:** • CI Breakdown
#25 A	**CI Service Provided ICT** (Dimensionless) CI Service Provided ICT [CIi] = IF THEN ELSE (CI Running Operations ICT[CIi]>= CI Average Demand ICT[CIi] ,1,CI Running Operations ICT[CIi]/ CI Average Demand ICT[CIi]) **Description:** *Like* **CI Service Provided**. **Present in 1 view:** • Only ICT **Used by:** • CI Breakdown ICT
#26 Sub [sub]	**CIi** : Energy, ICT, Water, Food, Health, Financial, Public and legal order and safety, Civil administration, Transport, Chemical and nuclear industry, Space and research **Present in 2 views:** • All CIs • Only ICT **Used by:** • CI Breakdown • CI Breakdown ICT • CI Disruption • CI Disruption Timeline • CI Disruption Timeline Trigger

Type	Variable Name and Description
	• CI Down Operations • CI Down Operations ICT • CI Return to Service • CI Return to Service ICT • CI Running Operations • CI Running Operations Drop Value • CI Running Operations Drop Value Accumulation Area under Curve ICT • CI Running Operations Drop Value Accumulation • CI Running Operations Drop Value ICT • CI Running Operations ICT • CI Service Provided • CI Service Provided ICT • CIj • Comparison Results • Delayed CI Disruption • Effect of CIj Failure on CIi • Effect of CIj Failure on CIi ICT
#27 Sub [sub]	**CIj** : Energy, ICT, Water, Food, Health, Financial, Public and legal order and safety, Civil administration, Transport, Chemical and nuclear industry, Space and research **Present in 2 views:** • All CIs • Only ICT **Used by:** • Effect of CIj Failure on CIi • Effect of CIj Failure on CIi ICT
#28 C 	**CIs Effects Considered** (Dimensionless) CIs Effects Considered [CIj] = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 **Description:** *The slected CIs to consider their Failure Effects on other CIs.* **Present in 1 view:** • All CIs **Used by:** • Effect of CIj Failure on CIi
#29 C 	**CIs Effects Considered ICT** (Dimensionless) CIs Effects Considered ICT [CIj] = 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0 **Description:** *Like* **CIs Effects Considered**. **Present in 1 view:** • Only ICT **Used by:** • Effect of CIj Failure on CIi ICT
#30 A 	**Comparison Results** (Dimensionless) Comparison Results [CIi] = 100*ZIDZ((CI Running Operations Drop Value Accumulation[CIi]-CI Running Operations Drop Value Accumulation Area under Curve ICT[CIi]),CI Running Operations Drop Value Accumulation Area under Curve ICT[CIi]) **Present in 1 view:** • All CIs **Used by:** **This is a supplementary variable.**
#31 DE	**Delayed CI Disruption** (Dimensionless/Hour) Delayed CI Disruption [CIi] = DELAY FIXED (CI Disruption[CIi] ,TIME STEP ,0) **Present in 1 view:** • All CIs **Used by:** • CI Disruption Timeline Trigger

Type	Variable Name and Description
#32 A	**Effect of CIj Failure on CIi** (Dimensionless) Effect of CIj Failure on CIi [CIi,CIj] = CIs Effects Considered[CIj]*Effect of CIj Failure on CIi Data[CIi,CIj] (CI Disruption Timeline[CIj]* Unit Normalization) **Description:** *The effect each CI has on the other based on the PhD thesis of Ana Lauge.* **Present in 1 view:** • All CIs **Used by:** • CI Breakdown
#33 T,D,A	**Effect of CIj Failure on CIi Data** Effect of CIj Failure on CIi Data [CIi,Energy] = GET XLS LOOKUPS('data_sheet_all.xlsx','Energy','a','b3') Effect of CIj Failure on CIi Data [CIi,ICT] = GET XLS LOOKUPS('data_sheet_all.xlsx','ICT','a','b3') Effect of CIj Failure on CIi Data [CIi,Water] = GET XLS LOOKUPS('data_sheet_all.xlsx','Water','a','b3') Effect of CIj Failure on CIi Data [CIi,Food] = GET XLS LOOKUPS('data_sheet_all.xlsx','Food','a','b3') Effect of CIj Failure on CIi Data [CIi,Health] = GET XLS LOOKUPS('data_sheet_all.xlsx','Health','a','b3') Effect of CIj Failure on CIi Data [CIi,Financial] = GET XLS LOOKUPS('data_sheet_all.xlsx','Financial','a','b3') Effect of CIj Failure on CIi Data [CIi,Public and legal order and safety] = GET XLS LOOKUPS('data_sheet_all.xlsx','Public & legal order & safety','a','b3') Effect of CIj Failure on CIi Data [CIi,Civil administration] = GET XLS LOOKUPS('data_sheet_all.xlsx','Civil administration','a','b3') Effect of CIj Failure on CIi Data [CIi,Transport] = GET XLS LOOKUPS('data_sheet_all.xlsx','Transport','a','b3') Effect of CIj Failure on CIi Data [CIi,Chemical and nuclear industry] = GET XLS LOOKUPS('data_sheet_all.xlsx','Chemical and nuclear industry','a','b3') Effect of CIj Failure on CIi Data [CIi,Space and research] = GET XLS LOOKUPS('data_sheet_all.xlsx','Space and research','a','b3') **Present in 2 views:** • All CIs • Only ICT **Used by:** • Effect of CIj Failure on CIi • Effect of CIj Failure on CIi ICT
#34 A	**Effect of CIj Failure on CIi ICT** (Dimensionless) Effect of CIj Failure on CIi ICT [CIi,CIj] = CIs Effects Considered ICT[CIj]*Effect of CIj Failure on CIi Data[CIi,CIj] (CI Disruption Timeline[CIj]* Unit Normalization) **Description:** *Like* **Effect of CIj Failure on**. **Present in 1 view:** • Only ICT **Used by:** • CI Breakdown ICT
#35 A	**Fastest Draining Time** (Hours) = TIME STEP **Present in 1 view:** • All CIs **Used by:** • CI Breakdown
#36 A	**Fastest Draining Time ICT** (Hours) = TIME STEP **Present in 1 view:** • Only ICT **Used by:**

Type	Variable Name and Description
	• CI Breakdown ICT
#37 C 	**FINAL TIME** (Hour) = 1440 **Not Present In Any View**
#38 C 	**INITIAL TIME** (Hour) = 0 **Not Present In Any View** **Used by:** • Time
#39 C 	**Max Effect of CIj Failure on CIi** (Dimensionless) = 5 **Description:** *Normalize all e(ij) by dividing each by the max possible value, which is 5.* **Present in 1 view:** • All CIs **Used by:** • CI Breakdown
#40 C 	**Max Effect of CIj Failure on CIi ICT** (Dimensionless) = 5 **Present in 1 view:** • Only ICT **Used by:** • CI Breakdown ICT
#41 C 	**SAVEPER** (Hour) = 12 **Description:** *The frequency with which output is stored.* **Not Present In Any View**
#42 C 	**Time between CI Disruption Durations** (Hours) Time between CI Disruption Durations [CIi] = 720, 720, 720, 720, 720, 720, 720, 720, 720, 720, 720 **Description:** *to generate a several disruptions, the value of this variable needs to be less than the final time of the model.* **Present in 1 view:** • All CIs **Used by:** • CI Disruption
#43 C 	**TIME STEP** (Hour) = 0.125 **Present in 2 views:** • All CIs • Only ICT **Used by:** • Delayed CI Disruption • Fastest Draining Time • Fastest Draining Time ICT
#44 C 	**Unit Normalization** (Dimensionless/Hour) = 1 **Description:** *The normalizing factor which ensures the units for the e(ij)-factors are coherently Dimensionless/Hour.* **Present in 2 views:** • All CIs • Only ICT **Used by:** • CI Breakdown

Type	Variable Name and Description
	• CI Breakdown ICT • Effect of CIj Failure on CIi • Effect of CIj Failure on CIi ICT

Simulation Analysis of Fire Hydrant Usability Levels after Large Earthquake

Toshihiro Osaragi
Tokyo Institute of Technology
osaragi.t.aa@m.titech.ac.jp

Noriaki Hirokawa
Tokyo Institute of Technology
hirokawa.n.aa@m.titech.ac.jp

ABSTRACT

Since large earthquakes can disrupt water supply networks, it is essential to gain an understanding of the expected usability of fire hydrants in post-quake firefighting activities. In this study, data about water supply networks was collected and a water outage simulation model was constructed in order to predict the likelihood that individual fire hydrants would become unusable in the wake of a large earthquake. The water outage simulation model was integrated with a previously developed urban zone damage simulation and a fire department activity simulation in order to carry out a simulation-based analysis of the 23 wards of Tokyo, after which a quantitative analysis of the relation-ship between use of fire hydrants and the number of buildings lost to fire was performed. This analysis revealed the benefits of hardening water lines against earthquakes, fire hydrant usage variations depending on locality, and the benefits of using water pressure sensors to identify usable fire hydrants.

Keywords

large earthquake, hydrant, water outage, fire-spread, firefighter.

INTRODUCTION

Research background

When multiple fires break out simultaneously, it is vital to identify and quickly extinguish those that have the highest risk of spreading. However, in the immediate aftermath of a large earthquake, it can be expected that responding fire departments will be delayed by street blockages and further hampered by inadequate supplies of water due to water outages at fire hydrants and/or low supplies in fire cisterns. Therefore, it is essential to establish comprehensive strategies for firefighting that not only account for fire spread but also consider street blockages, water outages, and other obstacles. Such a comprehensive study has never been done before.

In this study, we have combined a large-scale fire spread simulation model and an urban zone damage simulation model developed by Hirokawa and Osaragi (2016a, 2016b, 2017) by incorporating a street blockage simulation model into a fire department activity simulation model, and have used an index of fire spread risk (fire spread potential) to demonstrate the potential for immediate deployment of firetrucks in order to greatly reduce the number of buildings lost to fire. These models employed the assumptions of earlier studies (Fujii and Itoigawa, 2017; Sasaki and Sekizawa, 2014) that showed water would only be available from sources other than fire hydrants (fire cisterns, rivers, etc.). More specifically, they did not sufficiently scrutinize the actual usage availability of fire hydrants. However, efforts have been made to harden fire hydrants against earthquakes in recent years, so an investigation of the usability of fire hydrants incorporating water outage considerations is needed in order to facilitate a more exhaustive examination of firefighting activities in the event of a large earthquake.

The Tokyo Fire Department (TFD) (2015) and Takada et al. (2005) have published studies regarding the use of fire hydrants after a large earthquake. The TFD analysis was based on an exhaustive simulation model incorporating activities initiated upon learning of a fire, activities in gathering of fire department personnel, time for preparing the hose, and other factors. However, that fire hydrant usage analysis focused on early fire extinguishing activities by residents rather than by TFD firefighting teams. Additionally, the modeling of water outage consequences went no further than a simple representation in which the number of fires expected to be extinguished was multiplied by the rate of ordinary water delivery conditions (1.0 – water outage rates). The

analysis was based on the mean rate of water outages for each city, ward, town, or village according to damage estimate for Tokyo (Tokyo Metropolitan Government, 2012). Accordingly, as will be described later in this study, no details related to water line damage between water supply points and fire hydrants were considered.

Takada et al. (2005) examined records from the Great Hanshin Earthquake, in which numerous fire hydrants became unusable, and stated that personal suffering would have been significantly reduced if those fire hydrants had been operable. In their detailed analysis of the reasons for failures to prevent fires from spreading (insufficient water, etc.), in which they examined the times of fire breakouts and firetruck arrival times, among other factors, they provided much to consider in the drafting of this fire hydrant usability investigation. Nevertheless, prior to this study, the usability of fire hydrants to stop spreading fires in the immediate aftermath of a large earthquake has only been examined in a qualitative fashion.

Turning to studies with water outage simulations, post-quake Tokyo damage estimates (Tokyo Metropolitan Government, 2012) examined both the types and diameters of water lines, block-by-block, throughout Tokyo, along with ground velocities and potential of liquefaction indexes (*PL* values) in an effort to predict water outage rates. According to the Japan Water Research Center (2011), water outage rates can also be estimated using the characteristics of ground surface layers instead of the liquefaction index. In these studies, the damage occurring, in terms of the rate of water outages and other problems, was estimated using data about the lengths of buried pipes, information about the ground surface layers, and other data tabulated for each portion of the cell in the model. However, actual damage such as water outages does not occur in the cell units. Instead, they are considered as components of a networked structure (the water supply network) branching out from the water supply point. More specifically, this approach did not account for the downstream effects of damage to water mains at the network origin (i.e., near the water supply point), and could well have underestimated water outage rates at fire hydrants far downstream from the water supply point.

Research objectives

When there are no limits on the volume of available water and a high density of installed fire hydrants are available for use, we can expect firefighters to perform their duties efficiently, which will reduce the damage resulting from fires. However, a review of previous studies has turned up no investigations of the actual usability of individual fire hydrants in a water supply network structure that has suffered damage in the immediate aftermath of a large earthquake. The assumption that only fire cisterns, rivers, streams are available can be thought of as one possible assumption, when we consider an uncertain disaster situation after the occurrence of a huge earthquake. It can also be thought of as one reasonable assumption to lead the serious evaluation of disaster. Nevertheless, even any small resources that might be available after the disaster should be utilized to assist firefighting activities.

Therefore, in this study, we constructed a simulation model of fire hydrants in a water supply network suffering outages in the aftermath of a large earthquake. In order to analyze with consideration of the availability of each individual fire hydrant, it is necessary to construct a model that can describe the damage of each water pipe. The most unique viewpoint and the principal originality of this research is that we constructed the detailed simulation model which describes water outages by modeling the damage of individual water pipe, that has not been discussed yet in the previous research. Also in order to accomplish comprehensive and complex simulation analyses, we utilized some sophisticated models developed by Hirokawa and Osaragi (2016a, 2017, 2016b). They integrated previously proposed urban zone damage simulation models and a TFD activity simulation model, and used the result to observe ways in which the spread of fire could be halted in order to examine strategies for firefighting during a water outage. Since the installation of water pressure sensors was assumed to have been completed (Nikkei, 2016) by the TFD, it was also assumed that water outages at hydrants could be remotely detected. This novel analysis never done before is outcomes based on the detailed simulation model of water outages developed in this research. Using the analysis results, the reduction in the number of buildings lost to fire was demonstrated and the potential for retaining the usability of fire hydrants was examined.

SIMULATION OF THE WATER SUPPLY NETWORK AND OF A WATER OUTAGE

Water outage simulation overview

Our simulation of a water outage at fire hydrants consisted of (1) the assumed water supply network, (2) the assumed damage to individual water lines, and (3) the hydrants assumed to have been cut off from the water supply. However, since actual data about the water supply networks are unavailable due to security considerations, street network data were used to deduce the water supply network layout. Next, the water lines assumed to have suffered damage were selected on the basis of the *PL* value, the peak ground velocity (*PGV*), and the physical properties of the pipes. Finally, the water supply network was reconstructed while treating the damaged water

lines as unable to carry water, and the possibility of water supply from the purification plant to every fire hydrant was calculated to identify the unusable hydrants.

Method for deducing water supply network layout

Kobayashi et al. (2013) proposed a method for deducing the layout of water supply networks from street network data based on the fact that the supply lines for water, natural gas, and other utilities are generally buried beneath streets or roads. They showed that as long as grade separated intersections do not overlie the buried water lines and that the private roadways that are not included in district data are neglected, this method can provide highly precise data for densely inhabited districts (DID), which have pronounced needs for water lines.

Since most of Tokyo meets the DID definition, this study also employed the above procedure for deducing the water supply network locations (Fig. 1(1)). Next, the purification plants and fire hydrants were located on the street network data (Fig. 1(2)) and the directions of water supply through the networks were estimated from each network origin (purification plant) to the endpoint at each fire hydrant. It was assumed that water supply would be by the shortest route from a purification plant to a fire hydrant, and that route was found using Dijkstra's algorithm (Dijkstra, 1959) for searching for a path (Fig. 1(3)). Additionally, since there were multiple purification plants, calculations were carried out while assuming multiple independently operating water supply networks with origins at each purification plant.

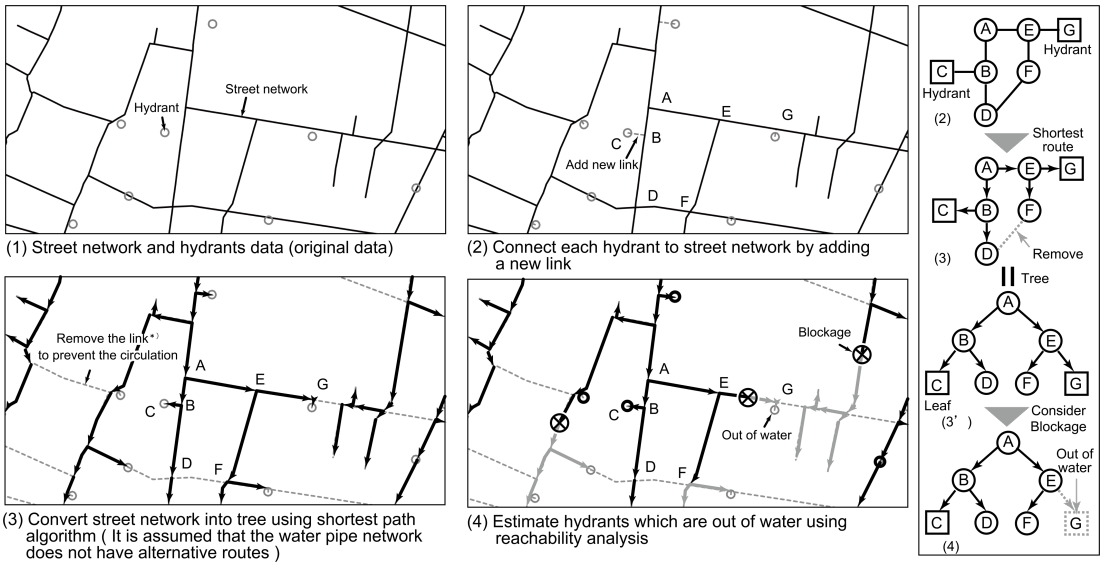


Figure 1. Construction of water pipe network and estimation of water outage

Damage prediction method for individual water lines

The occurrence of damage to any single water line is independent of the conditions of other lines. In this study, the damaged locations were predicted using the water line damage model contained in the damage estimate for Tokyo (Eq. (1)), which considered local *PL* values in order to provide exhaustive damage predictions (Tokyo Metropolitan Government, 2012).

$$E_D = 2.24 \times 10^{-3} \times C_{PL} \times C_D \times (PGV - 20)^{1.51} \times L \qquad (1)$$

where E_D is the number of damaged locations in a water line. *PGV* is the peak ground velocity (cm/sec), *L* is the length of each pipe section (m), and C_{PL} is a correction coefficient based on the *PL* value for the soil surrounding any given water line (Fig. 2). The *PL* values were estimated by converting the image data provided in the damage estimate for Tokyo into vector data. C_D is a correction coefficient that varies with pipe type and diameter. However, since these data were unavailable, it was assumed that the pipe type was ordinary ductile cast iron (without earthquake-resistant joints) and pipe diameters were estimated from street widths.

$$P_D(k) = \frac{(-E_D)^k \, exp(-E_D)}{k!} \qquad (2)$$

$$1 - P_D(0) = 1 - exp(-E_D) \quad (3)$$

Furthermore, assuming that the probability of breakage at each part in the water distribution pipe is uniform and independent for each part, the probability that the number of damaged parts is k at the length L (km) becomes Poisson distribution, and it can be expressed by Eq. (2) using the value of E_D. That is, the probability of occurrence of one or more breakages is expressed by Eq. (3).

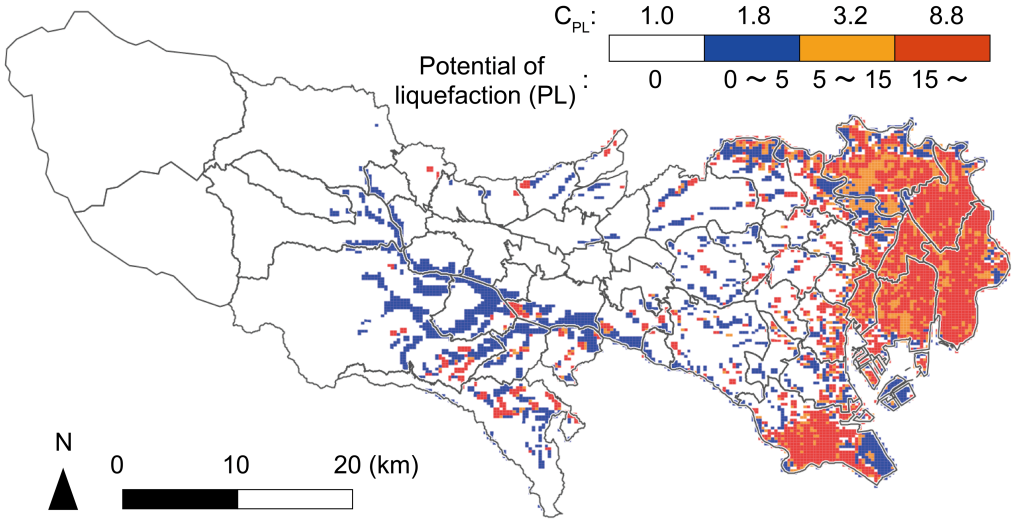


Figure 2. Potential of liquefaction (PL) in Tokyo Metropolitan area

Method for predicting outages at fire hydrants

Water outages were predicted based on the potential for damage along the water supply route from the purification plant to the fire hydrant and taking into consideration the possibility that damaged water lines in the network will no longer carry water (Fig. 1(4)). However, outages were specified only for fire hydrants that were determined to have become unable to receive water from any connected purification plant.

URBAN ZONE DAMAGE SIMULATION AND FIRE DEPARTMENT ACTIVITY SIMULATION

Overview of urban zone damage simulation

Using the urban zone damage simulation models and integrated a new model that allows users to predict physical damage due to collapsing buildings, street blockage, and spreading fires in urban zones, etc., at the level of individual buildings and streets. More specifically, the extent of destruction in the examined urban zone is estimated by the procedure shown in Fig. 3 using the ground surface response (Bureau of Waterworks Tokyo Metropolitan Government , 2016; Wakamatsu and Matsuoka, 2008; Fujimoto and Midorikawa, 2003; Matsuoka and Midorikawa, 1994; Si and Midorikawa, 1999), building collapse data (Midorikawa et al., 1994; Murao and Yamazaki, 1999), street blockage data (Murao and Yamazaki, 2000; Ministry of Land, Infrastructure and Transport, 2003), and the breakout and spread of fires (Ieda et al., 1998; Tokyo Fire Department, 1997, 2001).

First, the data about the ground surface layers, buildings, and earthquake source parameters were loaded into the ground surface response model on a 250-m cell. The seismic response at the ground surface (*PGV*, peak ground velocity) was then estimated at the level of individual buildings. Next, the number of buildings suffering complete collapse was predicted using the estimated *PGV* and the data for construction year (five classifications: prior to 1970, 1971-1980, 1981-1990, 1991-2000, 2001, and thereafter), and construction type (three classifications: wood, ferroconcrete/steel-framed reinforced concrete, and steel frame).

Based on these results, predictions were made as to which streets which would be blocked due to the complete collapse of adjacent buildings, which allowed us to envisage which streets would be rendered impassable for firefighters. This calculation was carried out for all the streets in the examined region. The outbreak or absence of building fires was calculated from the probability of an outbreak, which depended on the use of the building, the season, time of day, and the degree of structural damage. Outbreak times were distributed according to the TFD

survey results. The fire spread in the urban zone was estimated using a model that incorporates factors including the fire resistance properties of a given building to combustion itself, heat radiation from neighboring buildings, and spacing between neighboring buildings.

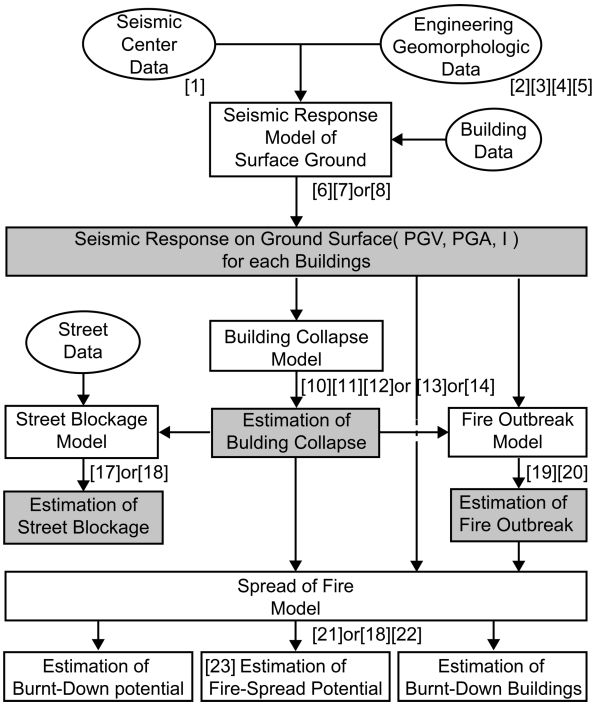


Figure 3. Outline of urban zone damage simulation model

Estimation of time limit for arrival of fire department to prevent fire spread

The time by which a fire department must arrive at a fire in order to prevent its spread (arrival time limit) is estimated based on the current fire spreading condition (fire circumference) in the fire spread simulation, whereas the maximum containable fire circumference is estimated by the number of responding firetrucks. In the simple method proposed by the TFD, a circle is drawn around the fire whose area equals the actual total floor area of the building on fire, and the circumference of this circle is used (Tokyo Fire Department, 2015). The TFD method is simpler but tends to underestimate the fire circumference as the fire spreads, which leads to overestimations of the arrival time limit. The method more closely represents the area to be sprayed with water under actual firefighting conditions (Fig. 4 left) should be used, however it requires very complicated calculation. In order to simplify analyses in this study, we only used more simple method by approximating the fire circumference with a convex envelope (Fig. 4 right). In the other, the fire circumference is represented by the length of the straight lines making up a convex envelope containing all the vertices of the polygon corresponding to the building on fire.

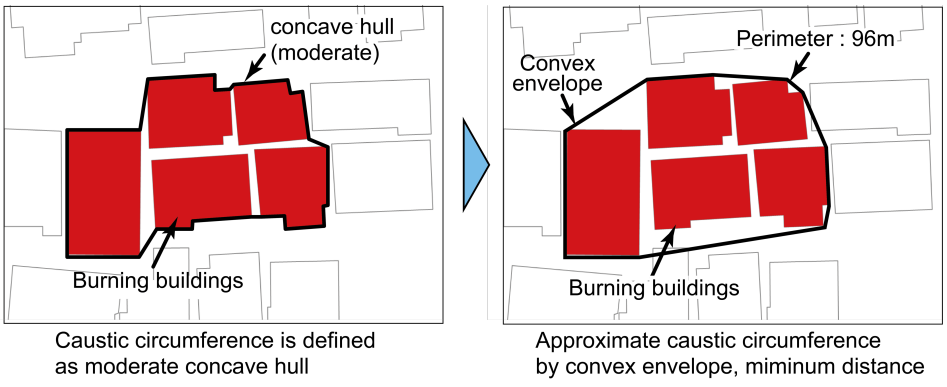


Figure 4. Approximate caustic circumference based on fire-spread simulation

Figure 5 shows the relationship between the elapsed time t since the fire breakout and the fire circumference $L(t)$ based on the mean values found in fire spread simulations incorporating all the buildings in Tokyo. D is the containable fire perimeter, the total actual portion of $L(t)$ that can be covered by the firefighters on site. D is determined by the number of responding firetrucks and the length of the sector assigned to each firefighting team. Then, Eqs. (4) and (5) determine the arrival time limits T_{lm}:

$$D = n \times d_a + m \times d_b \quad (4)$$

$$T_{lm} = L^{-1}(D) \quad (5)$$

where d_a represents the length of the sector assigned to a single fire department hose team and d_b represents the length of the sector assigned to a volunteer firefighter team. n and m indicate the respective numbers of hoses. In this study, it was assumed that a hose team was assigned two hoses and a fire front of 15 m (d_a = 15, n = 2), whereas a volunteer firefighter team was assigned one hose and a fire front of 10 m (d_b = 10, m = 1), and D was 40 m.

It should also be noted that even when the firetrucks arrived later than the arrival time limit (specifically, when [the sum of the time elapsed from the occurrence of the disaster to dispatch + travel time] was greater than [the sum of time elapsed from the occurrence of the disaster to fire breakout + arrival time limit]), by spraying selected portions of the fire, it is still possible to reduce the number of buildings lost to fire. However, that consideration was neglected in this study to avoid complications in calculating the number of losses.

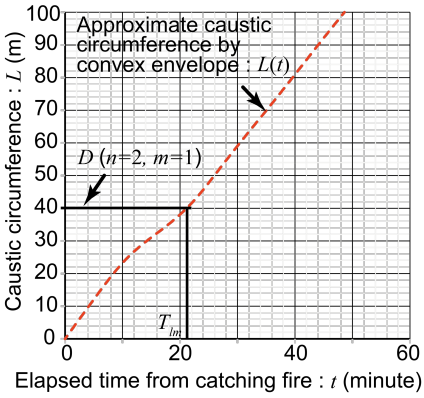


Figure 5. Average ratio of water outage and location of water purifying plant

Definition of fire spread potential inside a single building

The fire spread potential (Hirokawa and Osaragi, 2017), which is an index of the fire spread risk inside a single building, was defined using the results of fire spread simulations. The fire spread potential P_{Fi} of building B_i is defined using Eq. (6), and represents the final, total number of buildings that could be totally lost to fire if building B_i continued to burn freely.

$$P_{Fi} = \sum_{j \in BS} \delta_{ij}, \quad (6)$$

where variable δ_{ij} takes the value 1 if fire spreads from building B_i to building B_j and the value 0 otherwise, and BS is the set of all the buildings to be of concern.

Strategies for selecting dispatch destinations using fire spread potential

Because there is a fire which occurs after the time lag, we have to wait for a while and gather the information to judge fires with a relatively high fire spreading risk. In such a strategy based on standby, there is a danger of failing to prevent spreading fire. Therefore, using the fire spread potential and fire-outbreak probability for each building, we predict the ranking of the danger degree of a fire among all the fires that may occur as the result. Specifically, we calculate the expected value of the number of fires and its standard deviation by applying Eqs. (8) - (10) to the set of buildings whose fire spread potential within the jurisdiction k represented by the expression (7) is EP or more (Fig. 6). Thus, we can obtain the value of the fire spread potential, EP_k^*, that minimizes the value of Eq. (11).

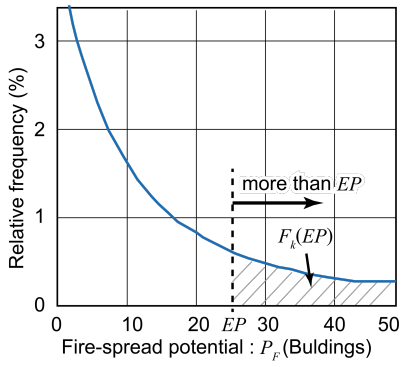


Figure 6. Relative frequency of Fire-spread potential

$$Bs_k = \{ (ep_{ki}, use_{ki}, I_{ki}) \mid ep_{ki} \geqq EP \} \quad (7)$$

$$E(X_k) = \sum_{b_{ki} \in B_{sk}} P(b_{ki}) \quad (8)$$

$$V(X_k) = \sum_{b_{ki} \in B_{sk}} P(b_{ki})(1 - P(b_{ki})) \quad (9)$$

$$P(b_{ki}) = P(use_{ki}, I_{ki}, S) \quad (10)$$

$$EP_{k*} = argmin_{EP} \left(|E(X_k) + \gamma_k \sqrt{V(X_k)} - Np_k| \right) \quad (11)$$

where, Bs_k is a set of buildings whose fire spread potential is EP or more within the jurisdiction k. ep_{ki}, use_{ki}, I_{ki} are the fire spread potential of the building B_{ki}, use and seismic intensity, respectively. X_k is a stochastic variable representing the number of fire in jurisdiction k, and its expected value and variance are denoted by $E(X_k)$ and $V(X_k)$, respectively. $P(b_{ki})$ is the probability of fire outbreak of the building B_{ki}, and S is a variable common to all buildings such as season and time. Np_k is the number of firetrucks in jurisdiction k, and γ_k is a parameter to be set according to characteristics of the urban area in order to cope with the fluctuation of stochastic event.

Fire department activity simulation accounting for water outage

The series of activities of a fire department responding to a fire were modeled as follows: The firetruck moves to an optimal water source for fire extinguishing activities, and the firefighting team carries a hose from the water source to the burning building (Fig. 7). The firetruck and the firefighting team speeds were set to different values ($speed_{Ve}$ and $speed_{Ff}$, respectively), and the passable streets (streets at least 4 m in width, all streets) were differentiated between for the firetruck and firefighting team. The optimal water sources were determined using Eq. (12).

$$WS_* = argmin_{ws \in WS} \left(\frac{D_n(ff, ws)}{speed_{Ve}} + \frac{D_e(ws, fire)}{speed_{Ff}} \right) \quad (12)$$

where WS_* represents the optimal water source, WS is the set of all water sources, $D_n(A, B)$ represents the distance from A to B in the network, $D_e(A, B)$ represents the straight-line distance from A to B, and *ff*, *ws* and *fire* represent the locations of a firefighting team, a water source, and a burning building, respectively. Four cases can be anticipated when selecting a water source: (1) No fire hydrant usage (use only of fire cisterns, rivers, streams, etc.); (2) fire hydrant use (no water outages); (3) fire hydrant use (possibility of water outages); and (4) use of fire hydrants (known water outages). When anticipating the use of fire hydrants (Cases (2), (3) and (4)), fire cisterns, rivers and streams are used in addition to fire hydrants. In Case (3), if the fire hydrants at the destination have no water pressure, fire hydrant use must be abandoned and other sources must be sought. Case (4) assumes that individual fire hydrants have been installed with water pressure sensors (Nikkei, 2016) and that water outages at hydrants can be remotely detected.

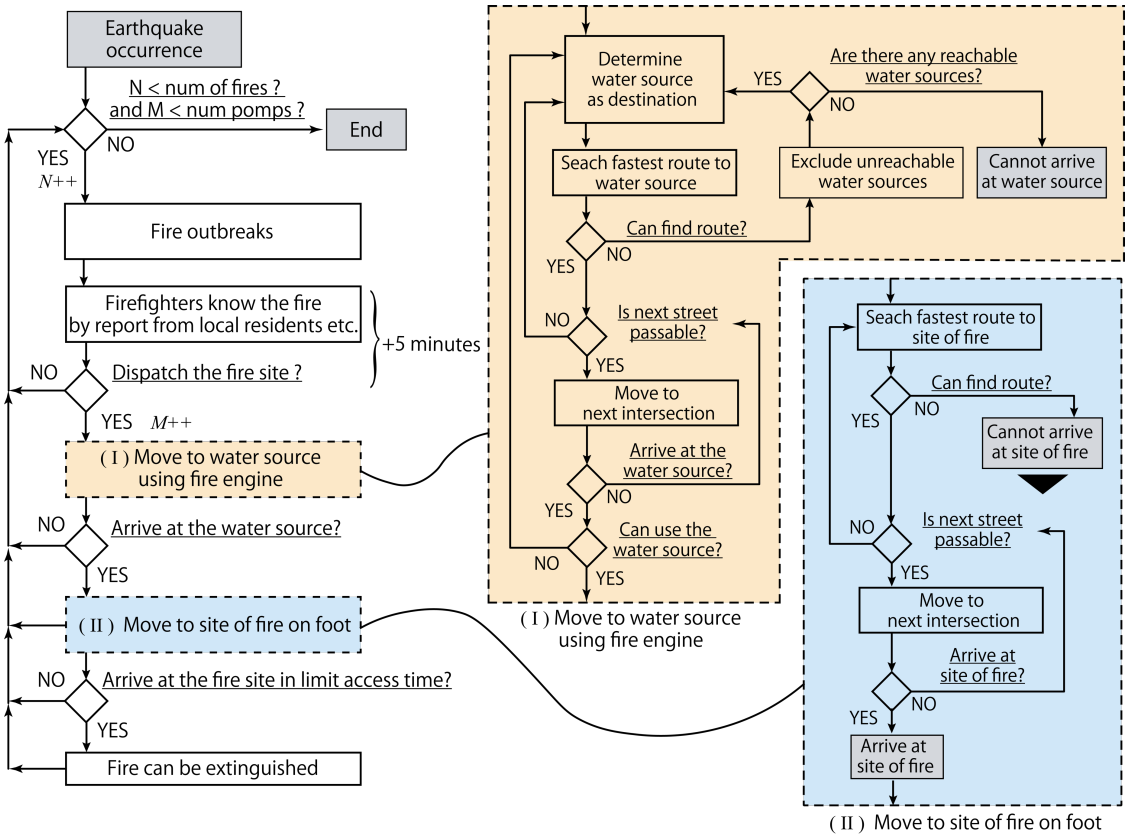


Figure 7. Outline of firefighter simulation model

In the urban zone damage simulation, it is also assumed that some streets will be blocked when calculating the time necessary to arrive at a burning building. Specifically, the simulation uses the following process. First, a path to the optimal firefighting water source is identified while assuming that all streets are passable. If blockage makes a street along the way impassable, a new path is then plotted from that location to the optimal firefighting water source. This process is assumed to take 30 seconds for the path search, course revision, etc. All the impassable streets found along the way are stored in memory and avoided when conducting new path searches. Additionally, when the firetruck has arrived at the firefighting water source and it turns out to be an unusable fire hydrant, the firetruck proceeds to another firefighting water source.

It is assumed that a combined team or number of teams, each consisting of a single fire station team and a volunteer firefighter team, are dispatched. The number of teams is the number of firetrucks held by the responding station and the branch fire stations. Considering the distribution of the clock times of fire breakouts in past damage data (Tokyo Fire Department, 2015) and the time needed for spraying, it was assumed that firetrucks are not deployed to other burning buildings after a fire has been controlled and that sufficient water is available for spraying the burning building being serviced. Note that half of the total number of fires that ultimately break out after a disaster do so within about 15 minutes after its occurrence, and 80% do so within the first 60 minutes.

SIMULATION CONDITIONS FOR THE COMPLETE TOKYO AREA AND WATER OUTAGE RATE PREDICTIONS

Target region for analysis and conditions for simulation

Urban zone damage simulations incorporating all of the buildings (2,784,101) and streets in Tokyo were carried out. The total of 1,000 simulations predicted varying physical damage situations (building collapse, street blockage, fire breakout/spread, and water outages) were conducted. A large earthquake with a magnitude of 7.3, centered in the north portion of Tokyo Bay on a winter evening (when the number of fire breakouts is likely to be the highest) was assumed. Other assumptions include a north wind of 8 m/sec and a humidity level of 50%.

The mean number of buildings lost to fire was estimated using the predicted physical damage, destinations for the fire stations (burning buildings) and arrival times in a Monte Carlo simulation (1,000 runs). The final numbers of buildings lost to fire were classified into those to which no firefighters were dispatched (free-burning fires) and

those to which firefighters were dispatched but were unable to prevent fires from spreading. However, a very consistent number of buildings succumbed to free-burning fires in these simulations. More specifically, the final numbers of buildings lost to fire depended solely on the number of burning buildings tackled by fire stations. Therefore, this discussion focuses solely on the number of buildings lost to fire due to failure to prevent fires from spreading.

Estimates of rate of water outages in water outage simulation

Figure 8 shows the figures for each ward in Tokyo for the fraction of the total number of unusable fire hydrants (rate of water outages) estimated by the water outage simulation. These rates were found to be high in the east and south parts of Tokyo, where liquefaction damage is expected to occur (Fig. 2) and in the west part of Tokyo, which has no nearby purification plants, while they were low in the north part of Tokyo, which has a number of local purification plants. The damage estimate for Tokyo predicted a water outage rate of 46.7% in wards with dense networks of water pipes and relatively numerous water supply points, while the authors' water outage simulation predicted a rate of 50.3% for the same locations. The discrepancy between these predictions is well within 10%. This consistency suggests that the outage estimates by our simulation were plausible.

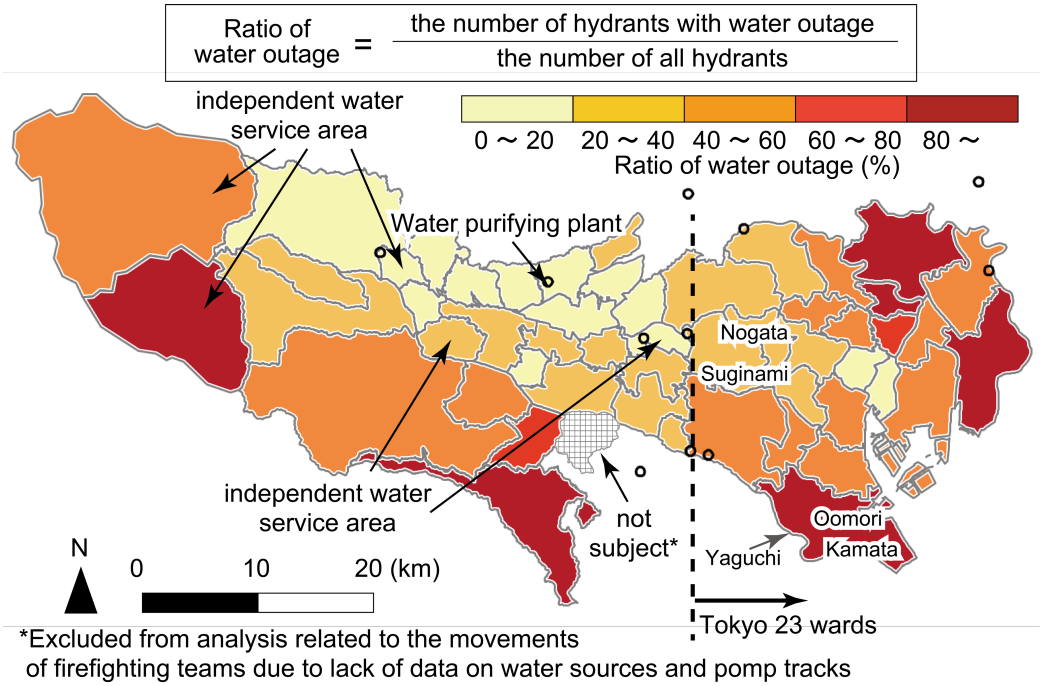


Figure 8. Average ratio of water outage and location of water purifying plant

INVESTIGATION OF USABILITY OF FIRE HYDRANTS IN FIREFIGHTING ACTIVITIES

Investigative method overview

In order to validate the effectiveness of utilizing fire hydrants for reducing the maximum number of buildings lost to fire, we examined that number while comparing the cases defined in 3.5 above. Comparing between Case (1) no usage of fire hydrants and Case (2) use of fire hydrants and no water outages, Case (2) corresponds to a situation in which individual water lines have been hardened against earthquakes (with earthquake-resistant joints, etc.) and will continue to function. Next, in order to examine the usability of fire hydrants during a water outage, we compare Case (1) no fire hydrant usage with Case (3) fire hydrant use and possible water outages. Finally, we observe the benefit of using fire hydrants by comparing Case (4) fire hydrant use (known water outages), which assumes that water outages at hydrants can be remotely detected with water pressure sensors that have been installed by the TFD, with Case (1) in which no fire hydrants are usable.

Effectiveness of fire hydrant used in reducing building losses

As an analysis reference of the effectiveness in reducing the number of buildings lost to fire, Fig. 9(1) provides

the spatial distribution of buildings lost due to the failure to prevent fire from spreading under Case (1). Here, it can be seen that the areas in which these losses were high form a wide ring within the 23 wards of Tokyo. Examination of the position densities of firefighting water sources other than fire hydrants (cisterns, etc.) in Fig. 10(1) show that many of the jurisdictions are underequipped with such sources. Comparing Case (1) with Case (2), it can be seen that the number of buildings lost to fire could be reduced in virtually all the jurisdictions (Fig. 9(2)). Figure 11 shows how the reduction in the number of buildings lost to fire varies with the water outage rates. Specifically, some jurisdictions could see reductions by about 100 buildings, and the jurisdiction with the maximum reduction in losses would see about 400 buildings saved (Fig. 11(1)). On the other hand, some of the jurisdictions with high fire hydrant densities showed little benefit in terms of the reduction in the number of buildings lost to fire (Figs. 9(2), 10(2)). This was ascribed to the small number of buildings lost to fire caused by the failure to prevent fire spread in the central portions of Tokyo and neighboring cities and to the fairly efficient positioning of firefighting water sources other than fire hydrants (firefighting water cisterns, etc.) (Fig. 9(1)).

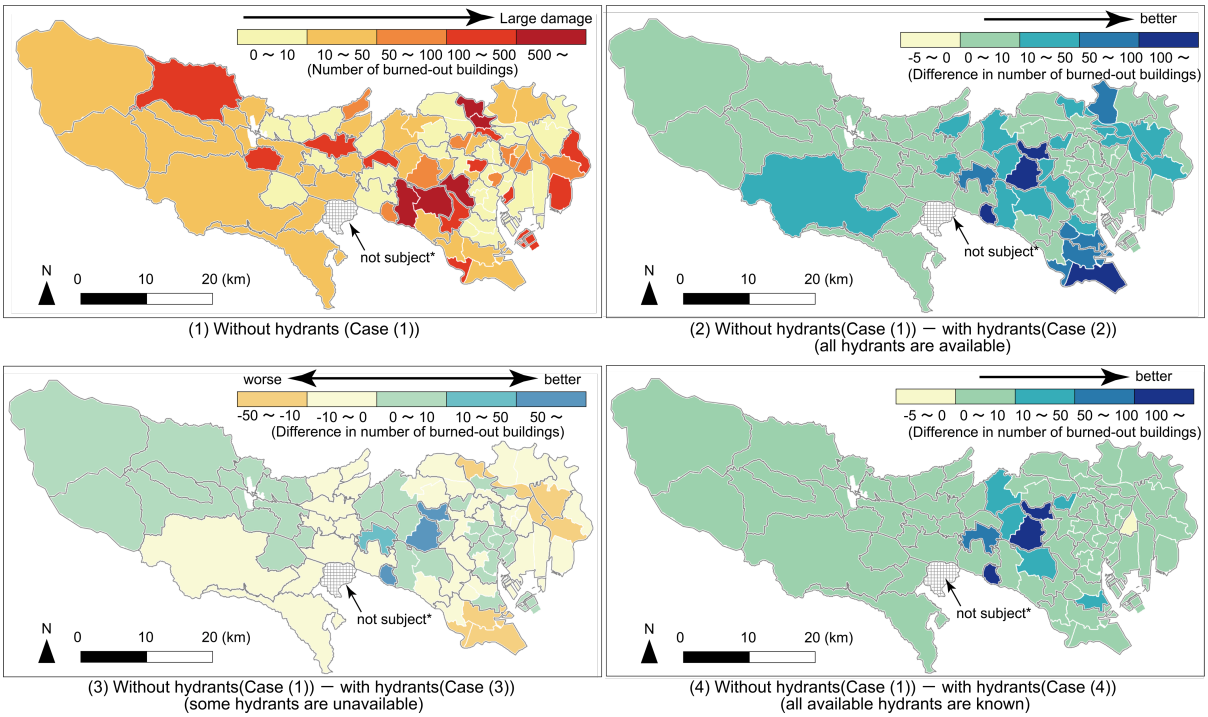


Figure 9. Difference in the number of burned-down buildings in each condition

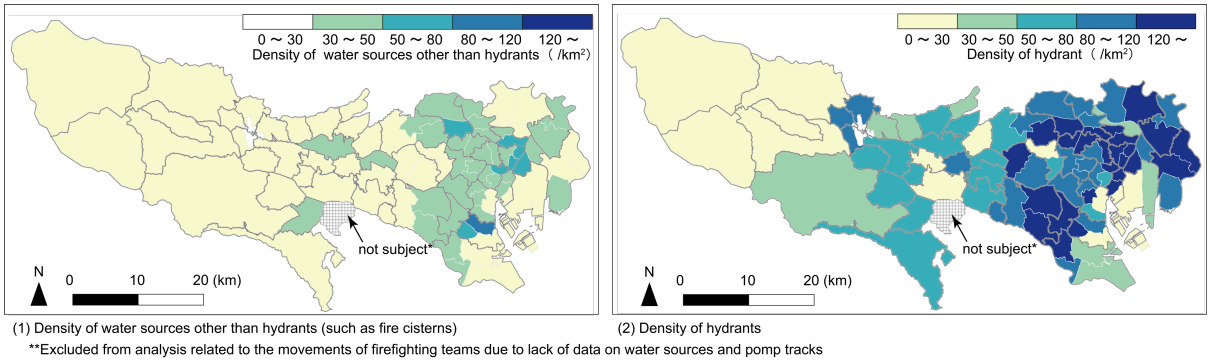


Figure 10. Density of water sources

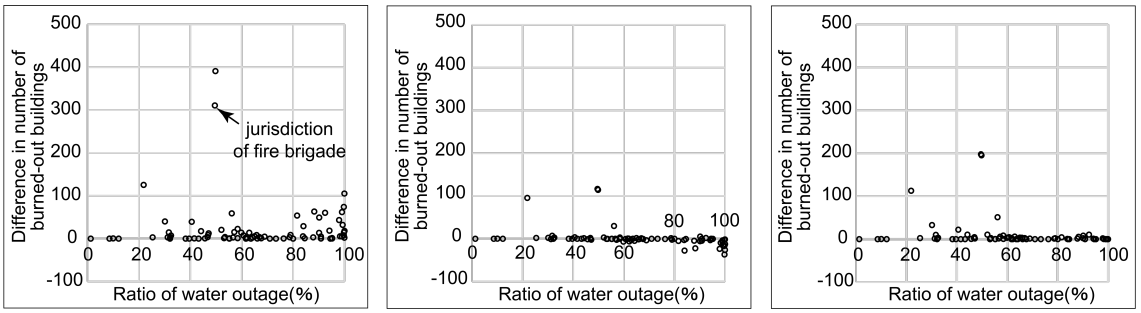


Figure 11. Relationship between difference in the number of burned-down buildings and the ratio of water outage

Influence of fire hydrants suffering water outages on number of buildings lost to fire

In Case (3), the use fire hydrants during potential water outages was attempted, but the number of buildings lost to fire increased in a total of 46 (56.1%) jurisdictions (Fig. 9(3)). However, the increase only exceeded 10 buildings in eight jurisdictions (9.76%), and was about 37 buildings at most (Fig. 11(2)). Additionally, some jurisdictions suffering water outage rates of around 50% were still able to save over 100 buildings, thus showing an advantage of using fire hydrants.

Benefit of reducing number of buildings lost by tracking unusable fire hydrants

Thanks to the introduction of water pressure sensors (Japan Water Research Center, 2011), in cases in which fire departments can verify which fire hydrants remain functional before they arrive at a fire (Case (4)), nearly all the jurisdictions were able to reduce building losses (Fig. 9(4)). Jurisdictions where water outages were less severe were able to reduce losses by nearly 200 buildings (Fig. 11(3)). However, since the jurisdictions that were able to cut losses by nearly 100 buildings under Case (2) were those suffering more severe water outages, we infer that there would be no benefit in terms of reducing building losses conferred by this technology under Case (4) (Fig. 9(4), Fig. 11(1), (3)). In such regions, i.e., regions with insufficient fire cisterns (Fig. 10(1)), the severe water outages mean fire stations cannot count on being able to use fire hydrants. Therefore, it is imperative to take other measures such as hardening water lines against earthquakes, constructing more fire cisterns, and so on.

Potential for use of fire hydrants during water outages

Here, while considering the above observations, we investigate the utility of fire hydrants in firefighting activities in spite of a water outage. If fire hydrants remain usable, some jurisdictions will be able to reduce the number of buildings lost by more than 400 units. However, the central portions of Tokyo and neighboring cities have fairly efficiently distributed firefighting water sources other than fire hydrants (fire cisterns, etc.), so many of those jurisdictions are in a position to carry out sufficiently effective firefighting activities in the event of a water outage without depending completely on fire hydrants. Nevertheless, assuming that water outages can be remotely detected, it is highly probable that the number of buildings lost to fire could be reduced in nearly all the jurisdictions, even after a large earthquake, which means that the introduction of water pressure sensors will be extremely beneficial.

Additionally, since jurisdictions that are less vulnerable to water outages were also able to save nearly 200 buildings, there needs to be more investigation of the use of fire hydrants in such areas. Figure 12 shows the numbers of buildings that posed difficulties for firefighting activities when no fire hydrants were available, as estimated from the locations of firefighting water sources other than fire hydrants and firefighter hose lengths. There are approximately 20,000 buildings in the complete area of Tokyo which will be difficult to access by firetrucks if no fire hydrants are available. Thus, fire hydrants are crucial. In contrast, regions that have sufficient numbers of fire hydrants but are prone to water outages will benefit less from information about local water outages, so in those areas it is important to harden water lines and construct more fire cisterns.

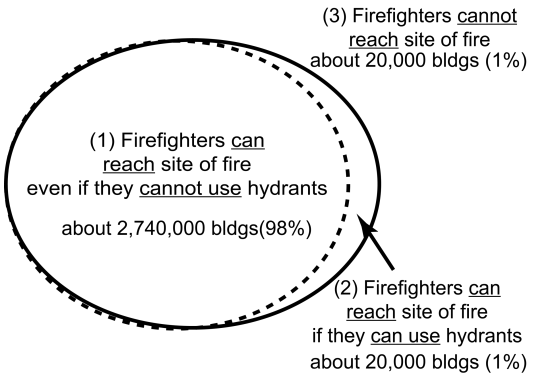


Figure 12. The number of burned-out buildings and difference in firefighters' reachability be-tween with/without hydrant

SUMMARY AND CONCLUSIONS

A simulation model was constructed in order to investigate the usability of fire hydrants during water outages following a large earthquake and to predict the occurrence of water outages at individual fire hydrants in a water supply network after such an earthquake. The authors also combined previously proposed simulation models of urban damage and fire department activities to quantitatively analyze the effects and benefits of fire hydrant usage in terms of reducing the number of buildings lost to fire.

From the results of the water outage simulation, it was determined that water outage rates will be higher in the east and south parts of Tokyo, where serious damage is expected due to soil liquefaction and in the west part of Tokyo, which is far from water purification plants. One of the most important results of this study has been the simulation model describing the phenomena of water outages occurring in water supply networks, which was used in place of the cell model previously employed for such simulations.

The simulation noted fire department jurisdictions in which more than 400 buildings were saved from complete fire destruction after a large earthquake because of the hardening of water lines that had been performed in those areas, which helped prevent water outages. A few jurisdictions saw a slightly greater damage rate when attempting to use fire hydrants during water outages, but jurisdictions that had low rates of water outage were able to reduce the number of buildings lost to fire by over 100. It was also determined that the central portions of Tokyo and neighboring cities are somewhat better equipped with firefighting water sources other than fire hydrants (fire cisterns, etc.) than the Tokyo suburbs.

Once Tokyo has completed its ongoing installation of water pressure sensors and water outages can be remotely detected as soon as they occur, nearly all jurisdictions will be able to save many more buildings from destruction by fire. Jurisdictions with lower rates of water outages (around 50%) will be able to save approximately 200 buildings. Additionally, there are about 20,000 buildings that fire departments would be unable to service without fire hydrants. Jurisdictions that are underequipped with fire cisterns and other backup sources of water should prepare to track water outages and plan to rely on fire hydrants.

In order to simplify water outage predictions, the water outage simulation in this study did not account for pressure losses due to leaks or the potential to continue some supply of water downstream of a breakage. Furthermore, it was assumed that the water supply network has a tree format when it actually has an interlinked format. Future research must include construction of a more exhaustive simulation model as the urban zone damage simulation mode used in this study did not account for effects such as street blockages or delays due to fleeing population, abandoned automobiles, or traffic jams. For that model, an approach using a physical model must also be examined.

ACKNOWLEDGMENTS

This paper is a part of the research outcomes funded by Core Research for Evolutionary Science and Technology (CREST) and Japan Science and Technology Agency (JST). A portion of this paper was published in the Journal of Architectural Planning and Engineering (Architectural Institute of Japan), in an article entitled “Availability of Hydrants after Large Earthquake: Simulation Analysis on Water Outage, Fire-spreading, and Firefighting”, 82 (739), pp.2185–2195, 2017 (in Japanese).

REFERENCES

Bureau of Waterworks Tokyo Metropolitan Government (2016) Water purifying plants and water service areas in Tokyo (accessed 2017-05-14), *https://www.waterworks.metro.tokyo.jp/suigen/map.html*

Dijkstra, E. (1959) A Note on Two Problems in Connexion with Graphs, *In Numerische Mathematik*, 1, 269-271

Fujii, K., Itoigawa, E. (2005) A Study on the Strategy of Fire Fighting Based on Information Collecting Activities by the Fire Department in Case of Post-Earthquake Fire, *Journal of Social Safety Science*, 7, 351-359

Fujimoto, K., Midorikawa, S. (2003) Average Shear-Wave Velocity Mapping throughout Japan Using the Digital National Land Information, *Journal of Japan Association for Earthquake Engineering*, 3(3), 13-27

Hirokawa, N., Osaragi, T. (2017) Fire-Spread Indices Based on Large-Scale Simulation in Case of Multiple Simultaneous Fires and Its Application for Assisting Firefighters, *Journal of Architecture and Planning* (*Transactions of AIJ*), 82(732), 301-310

Hirokawa, N., Osaragi, T. (2016a) Earthquake Disaster Simulation System: Integration of Models for Building Collapse, Road Blockage, and Fire Spread, *Journal of Disaster Research*, 11(2), 175-187

Hirokawa, N., Osaragi, T. (2016b) Access Time of Emergency Vehicles Under the Condition of Street Blockages After a Large Earthquake, First International Conference on Smart Data and Smart Cities, ISPRS Annals of the Photogrammetry, *Remote Sensing and Spatial Information Sciences*, IV-4/W1, 37-44

Hirokawa, N., Osaragi, T., Oki, T. (2014) Accessibility of Emergency Vehicles: Effects of Road-Blockage-Information in Large earthquake, *Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan*, 45-146

Ieda, J., Mochizuki, T., Kaminishi, S. (1998) Assessment of Vulnerability of Urban Areas to Street-Blockades Caused by Quake-Collapsed Buildings, *International Association of Traffic and Safety Sciences review*, 23(3), 138-145

Iwami, T., Ohmiya, Y., Hayashi, Y., Naruse, T., Takeya, S., Kagiya, K., Itoigawa, E., Kato, T., Shida, K., Hokugo, A., Takahashi, W. (2006) Development of Evaluation Methods for Fire Spread Risk in Urban Area, *BRI Research Report*, 145, 1-66

Japan Water Research Center (2011) Guidance for Estimation of Water Pipe Network Damage After an Earthquake, Development of the Updating Water Pipe Network Method, *Report of Estimation of Water Pipe Network Damage After an Earthquake*

Kobayashi, T., Yamazaki, F., Maruyama, K. (2013) Estimation of Water-Pipeline Length from GIS Road Network Data, *Journal of Social Safety Science*, 21, 267-274

Matsuoka, M., Midorikawa, S. (1994) The Digital National Land Information and Seismic Micro Zoning, *The 22nd Symposium of Earthquake Ground Motion, Architetural Institute of Japan*, 23-24

Matsuoka, M., Wakamatsu, K. (2008) Average Shear-wave Velocity (Vs30) Map Based on the 7.5-arc-second Japan Engineering Geomorphologic Classification Map, *National Institute of Advanced Industrial Science and Technology*, H20PRO-936

Midorikawa, S., Matsuoka, M., Sakugawa, K. (1994) Site effects on strong motion records observed during the 1987 Chiba-Ken-Toho-Oki, *Proceeding of 9th Japan Earthquake Engineering Symposium*

Ministry of Land, Infrastructure and Transport (2004) Developments of Technology and Evaluation index of Disaster Mitigation for planning Local Areas

Murao, O., Yamazaki, H. (1999) Comparison of Building Damage Evaluation by Local Governments after the 1995 Hyogoken-Nanbu Earthquake, *Journal of Architecture, Planning and Environmental Engineering* (*Transactions of AIJ*), 515, 187-194

Murao, O., Yamazaki, H. (2000) Development of Fragility Curves for Buildings Based on Damage Survey Data of a Local Government After the 1995 Hyogoken-nanbu Earthquake, *Journal of Structural and Construction Engineering* (*Transactions of AIJ*), 527, 189-196

Nikkei (2016) Water Supplies Will Be Restored Earlier in Big Earthquake

Osaragi, T., Hirokawa, N. (2015) Non-availability of Fire Hydrants and Choice of Firefighting Water-Supply, Summaries of Technical Papers of Annual Meeting, *Architectural Institute of Japan*, 247-248

Osaragi, T., Hirokawa, N. (2017) Simulation Analysis of Fire Brigade Action Strategies during Multiple

Simultaneous Fires, *Journal of Disaster Research*, 12(2), 311-319

Sasaki, K., Sekizawa, A. (2014) Risk Assessment of Fire Spread Potential for a Densely Built-up Area Using a Simulation Model of Fire Spread and Fire-fighting, *Journal of Japan Association for Fire Science and Engineering*, 64, 29-37

Si, H., Midorikawa, S. (1999) New Attenuation Relationships for Peak Ground Acceleration and Velocity Considering Effects of Fault Type and Site Condition, *Journal of Structural and Construction Engineering* (*Transactions of AIJ*), 523, 63-70

Takada, S., Gonsoku, Y., Kuwata, Y. (2005) Fire Spreading and Casualty due to Outage of Water at Hydrants, *Journal of Japan Association for Earthquake Engineering*, 5(2)

Tokyo Fire Department (2015) The Strategy for Alleviating Human Suffering Caused by an Earthquake Fire, *Report of Fire Prevention Council*

Tokyo Fire Department (1997) Provision and Elucidation of New Factor of Fire and Fire Spread Behavior Considering Inland Earthquakes, *Report of Fire Prevention Council*

Tokyo Fire Department (2004) Provision and Elucidation of Risk Factor after Large Earthquake in Civilization, *Report of Fire Prevention Council*

Tokyo Fire Department (2003) Development and Application of Evaluation Method for Preventing Ability of Earthquake Fire, *Report of Fire Prevention Council*

Tokyo Metropolitan Government (2012) Estimation of Earthquake Damage in Tokyo, *http://www.bousai.metro.tokyo.jp/japanese/tmg/assumption.html* (accessed 2015-01-28)

Wakamatsu, K., Matsuoka, M. (2008) Construction of the 7.5-arc-second Japan Engineering Geomorphologic Classification Map, *Summaries of technical papers of Annual Meeting Japan Association for Earthquake Engineering*, 222-223

Simulation Platform for Unmanned Aerial Systems in Emergency Ad Hoc Networks

Patrick Lieser*
KOM, Technische Universität Darmstadt,
Darmstadt, Germany
patrick.lieser@kom.tu-darmstadt.de

Julian Zobel*
KOM, Technische Universität Darmstadt,
Darmstadt, Germany
julian.zobel@kom.tu-darmstadt.de

Björn Richerzhagen
KOM, Technische Universität Darmstadt,
Darmstadt, Germany
bjoern.richerzhagen@kom.tu-darmstadt.de

Ralf Steinmetz
KOM, Technische Universität Darmstadt,
Darmstadt, Germany
ralf.steinmetz@kom.tu-darmstadt.de

ABSTRACT

Natural disasters regularly impede communication infrastructure, leaving civilians without reliable means of communication. In such cases, ad hoc networks enable basic communication inside the affected areas. However, low human mobility and group formation limit their performance, as messages are confined to distinct communication islands. Autonomous Unmanned Aerial Vehicles can help in spreading messages across multiple such islands, as proposed in the literature. Evaluating the resulting Unmanned Aerial System (UAS) under real-world conditions requires significant resources, e.g., field tests and prototypes. For a systematic assessment of a UAS and its support strategies under controlled conditions, simulations are the preferred method. To this end, we propose the first simulation platform that combines ad hoc communication on the ground and the corresponding human mobility models with an extensible model for a networked UAS and their respective support strategies. We implement and evaluate two representative strategies, showcasing the capabilities of the proposed platform.

Keywords

Simulation Platform, Unmanned Aerial Vehicles, Delay Tolerant Networks, Emergency Ad Hoc Networks

INTRODUCTION AND MOTIVATION

Recent disasters such as Hurricane Harvey in 2017 or Hurricane Florence in 2018 demonstrated the highly destructive force of natural disaster, and they revealed the strong dependencies of the civilian population on critical infrastructures such as energy supply or information and communication technologies (ICT). Particularly in the aftermath of a disaster the communication volume increases and the communication infrastructure can no longer cope with the high communication demand (Klinsompus and Nupairoj 2015). In such resource-constrained situations, however, where communication is key for successful emergency response operations, there is a need for civilian-centric emergency communication networks.

In 2017, we conducted a large field test throughout one day to show the capabilities of smartphone-based communication networks for emergency response (Álvarez et al. 2018). The field test took place at the military training area *Senne* near Paderborn in Germany in conjunction with experts from the German Federal Office of Civil Protection and Disaster Assistance (BBK), the German Federal Agency for Technical Relief (THW), local fire departments, and other NGOs. A large set of emergency services (Lieser, Alvarez, et al. 2017), such as SOS Messages, Person-Finder, or a Resource Market were available for 125 participants to cope with various scripted

*Equally contributing authors

Figure 1. The layout of the field test area (Álvarez et al. 2018).

disaster events in a realistic environment consisting of three different villages (Figure 1). The smartphones of the participants were used to build a large communication network which was based on the store-carry-forward principle known from delay-tolerant mobile ad hoc networks (DTN-MANETs) (Uchida et al. 2013). Message propagation was achieved in a flooding-based manner, where duplicates of all stored messages are forwarded every time a node discovers a new node in communication range. The field test demonstrated, on the one hand, that smartphone-based ad hoc networks can successfully be utilized to support emergency response efforts. On the other hand, the field test revealed the limited communication capabilities of DTN-MANETs which are highly dependent on the users' mobility to distribute messages.

Due to the high distance of Village B and C to Village A ($\approx 3.5\,km$ beeline, $\approx 5\,km$ by foot) and the natural human behavior of forming groups, the network was highly intermittent with large communication islands in and around the villages. Within these islands, communication performed well. Messages were distributed within a few seconds throughout an entire island. However, to achieve communication between distinct islands mobility is required for message transport. Participants, thus, would have to act as communication bridges between islands, but only a few of them actually moved between the villages, especially between the distant ones. Furthermore, if participants moved between the distant villages, it took them more than 60 minutes in most cases. Thus, lifetimes of most of the carried messages were already expired on arrival. Figure 2 displays the best and a median number of reached participants (out of 125) and the corresponding delivery delay within the message lifetime of 60 minutes. Instantaneous jumps indicate the distribution of a message when a new communication island is encountered, but the distances between those jumps show that it takes a long time for an encounter to happen.

During the field test, the interaction with the provided emergency services resulted in a total number of 1,835 unique messages which were duplicated and forwarded 18,418 times in the network. With a higher message lifetime, the number of reached participants would have further increased. However, this would also increase the amount of duplicates and therefore the network load resulting in more needed message storage space on the nodes. Furthermore, the relevance of a message or the relevance of the contained context information can decrease over time (Lieser, N. Richerzhagen, Luser, et al. 2019; Lieser, Alhamoud, et al. 2018).

Moreover, especially for high priority messages like SOS calls and warnings in emergency response services a timely delivery is crucial. Another example of the need to provide fast communication are tsunami warnings. For example after the Great East Japan Earthquake in March 2011, the affected population could not be warned sufficiently quickly of the upcoming tsunami because the effects of the earthquake had disrupted the communication in various regions (Ranghieri and Ishiwatari 2014). Thus, improving the performance of DTN-MANET emergency communication with regard to fast, reliable and thorough message propagation can significantly improve the efficiency of disaster relief and emergency response services and eventually saves lives.

In recent years, the increasing availability and popularity of small, commercially available Unmanned Aerial Vehicles (UAVs) has attracted remarkable attention from researches and practitioners. Besides their use for leisure activities, they proposed UAV application for example in search and rescue missions (Rémy et al. 2013; Scherer et al. 2015) or to relay communication of rescue team members on incident sites (Morgenthaler et al. 2012; Baumgärtner et al. 2017). Regarding the field test results, it became clear that inter-island communication cannot be efficient relying only on uncontrollable node movement. An Unmanned Aerial System (UAS), where multiple autonomous UAVs collaborate to efficiently support physical message transport between intermittent communication islands,

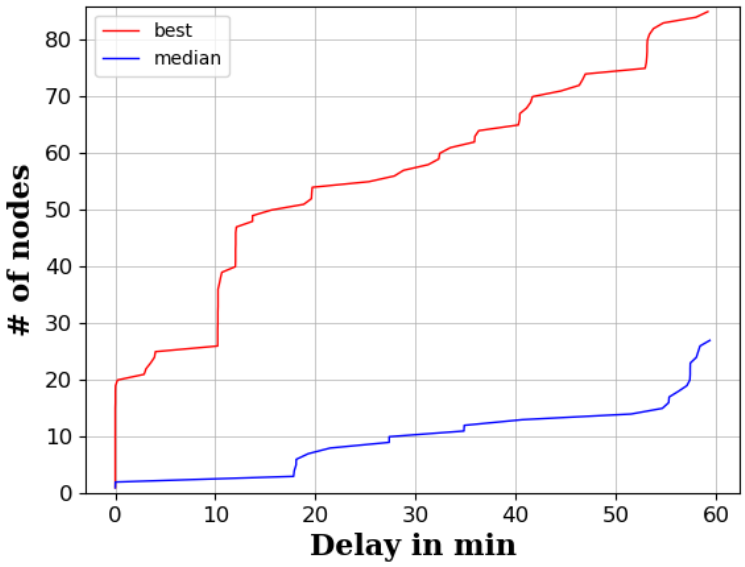


Figure 2. Number of reached nodes and the corresponding propagation delay during the field test. Messages had a lifetime of 60 minutes (Álvarez et al. 2018).

could provide a much more performant emergency communication. As drafted in Figure 3, a UAV could act as a communication bridge between otherwise intermittent communication islands and thereby, eliminate the necessity for ground nodes to move between islands for message dissemination.

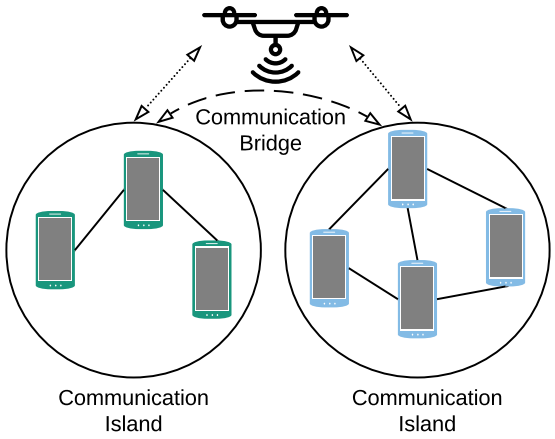


Figure 3. Communication amongst intermittent communication islands in a DTN-MANET requires nodes to act as communication bridges. UAVs are either acting as message relays by positioning themselves in communication range between two near islands, or by providing more efficient means of physical message transport between remote islands due to their mobility.

To design and to evaluate the applicability of such a system, field trials with prototypes or small testbeds are often conducted, and are indispensable to test the applicability of UAVs under realistic environmental conditions such as extreme weather conditions. However, this process has several drawbacks. On the one hand, an elaborate field test cannot be repeated on a regular basis due to the high costs and organizational complexity. Moreover, on the other hand, it would require already existing working prototypes to test them in the field, or at least in an experimental testbed.

Due to poor scalability, reproducibility, and possible law-restrictions, as well as the requirement of expensive hardware prototypes for experimental evaluations, performing simulations, is the preferred method for the development of complex systems. There exists no simulation platform that combines the possibility to simulate and evaluate Mobile Ad Hoc Networks on the ground in combination with Unmanned Aerial Systems, as discussed in the following

section. This paper, therefore, introduces a simulation platform for Unmanned Aerial Systems as an extension of the discrete-event open-source simulation and prototyping platform SIMONSTRATOR.KOM (B. Richerzhagen et al. 2015) for mobile networks. It can be used for the implementation, simulation, and evaluation of a large-scale UAS in combination with mobile communication networks on the ground. The modular system design allows the simulation of various behavioral strategies and a multitude of different UAV parameter settings.

As a proof of concept, we implemented and evaluated an Unmanned Aerial Communication Support System for civilian-centric post-disaster emergency communication networks based on our field test (Álvarez et al. 2018). Two simple, yet diverse behavioral strategies are provided in the prototype implementation, to show the potential extensive scope of systems our simulation platform allows to develop. The results show that we can significantly improve the communication characteristics of the DTN-MANET on the ground, by improving the message propagation while also decreasing the delivery delay. Our simulation platform can further be used to determine optimal UAS settings, such as the minimal amount of UAVs required to reach an intended message delivery rate or delay.

The remainder of this paper is structured as follows. In the next section, related work is described, followed by the concept and design presentation of our UAS simulation platform. Afterward, we present two possible behavioral strategies and their proof-of-concept evaluation in two different scenarios. Eventually, we conclude the paper and discuss future work approaches.

RELATED WORK

The possible destruction of ICT infrastructures in the aftermath of disasters led to the development of many infrastructure-independent post-disaster communication systems based on DTN-MANETs and a variety of different applications. George et al. 2010 propose the use of wireless sensor nodes for the provision of real-time situational awareness on site for search and rescue mission teams. The system combines on-demand and delay-tolerant routing for heterogeneous nodes with good performance results shown in simulations.

Serval Mesh (P. Gardner-Stephen, Challans, Lakeman, Bettison, D. Gardner-Stephen, et al. 2013), *Twimight* (Hossmann et al. 2011), and *TRIAGE* (Luqman et al. 2011) are also multi-purpose infrastructure independent communication system that can be used in the case of a disaster. These systems also support different prioritization mechanisms to handle the limited bandwidth in DTN-MANETs. As already proven in the field test (Álvarez et al. 2018) and other prototypical hardware demonstrations (Meurisch et al. 2017), decentralized civilian communication systems for post-disaster scenarios are possible by utilizing the ubiquity of civil smartphones. The SIMONSTRATOR.KOM platform (B. Richerzhagen et al. 2015) allows to simulate large-scale civilian ad hoc networks as shown, e.g., for decentralized resource allocation in disaster scenarios (Lieser, N. Richerzhagen, Feuerbach, Meuser, et al. 2018).

Dedicated communication modules such as the Serval Mesh Extender (Lieser, Alvarez, et al. 2017; P. Gardner-Stephen, Challans, Lakeman, Bettison, Lieser, et al. 2017) make it possible to communicate over long distances (tested with 4 km distance) independent of any fixed infrastructure. In principle, such devices would be ideal to connect communication islands, but they need a line of sight to reach the specified communication distances which are often not possible. Furthermore, experts need to have access to strategic places, such as the edge of a communication island for a meaningful deployment of the communication modules. The locations of the islands are also strongly dependent on the course of a disaster and are therefore difficult to predict.

Besides these system examples for post-disaster communication there exist a variety of different applications, specifically designed for DTN-MANETs. With the goal to help the affected population to cope with the aftermath of a disaster, such services allow civilians to send out distress signals (Al-Akkad et al. 2014; Mokryn et al. 2012), have text-based conversations, make it possible to find friends and family, or to share resources at a digital market-place (Lieser, Alvarez, et al. 2017; Lieser, N. Richerzhagen, Feuerbach, Nobach, et al. 2017). To boost message delivery rate in a wide-spread, sparsely populated DTN-MANET environment, Uchida et al. 2013 insert cars with WiFi capabilities as additional nodes into the network, similar to Zhao et al. 2004. The simulation was conducted in the ONE simulator[1] with the cars moving on the streets with up to $50\ \frac{km}{h}$. Results indicate that even with 100 cars it took more than 30 minutes on average for messages to travel 4 km between two rescue shelters. Furthermore, only 80% of the messages are delivered at all.

Proposed applications for Unmanned Aerial Systems include Search and Rescue missions (Rémy et al. 2013; Scherer et al. 2015), forest fire localization (Belbachir et al. 2015), inspection of infrastructure like power lines (Erdelj et al. 2017), aerial contamination measurement (Daniel et al. 2009), LTE coverage provision (Rohde et al. 2013; Li et al.

[1] http://akeranen.github.io/the-one/

2015), and message relaying for rescue team members on incident sites (Morgenthaler et al. 2012; Baumgärtner et al. 2017).

However, most of these applications used unique hardware prototypes to show their feasibility, or build mathematical models to provide insight into possible advantages and drawbacks, very few use simulations. A very basic simulation for UAV trajectories is used by Belbachir et al. 2015 and Erdelj et al. 2017 but neither the simulation tool nor the capabilities for realistic UAV simulations are stated. A discrete event simulation for UAVs is presented in Dietrich et al. 2017a including a 3D visualization. However, the tool is specifically designed to evaluate maintenance processes for long-term UAV deployments. Communication happens without limitations and with perfect reception only between a mission controller and the UAVs. In Mori et al. 2015 a large-scale simulation of very different nodes such as balloons, cars, and UAVs is shown. Entities build up a mesh network to provide communication between users. The simulator and its details, however, is not specified and nodes are either static or only use a random waypoint movement model, which insufficiently represents real-world behavior.

In conclusion, there are some approaches for the simulation of Unmanned Aerial Vehicles or comprising systems. However, they are limited in their applicability to general system development or lack certain features like realistic node movement or communication models. Most often, simulations are implemented specifically for the tested approaches and do not allow for the implementation of other systems.

Thus, a simulation tool which provides broad access to different movement and communication models allows the realistic simulation of different kinds of nodes like UAVs or smartphone users, and in particular is fit for the implementation and evaluation of diverse UAS as required for quick and large-scale development of such systems. There exists no simulation platform fulfilling these requirements.

SIMULATION PLATFORM FOR UNMANNED AERIAL SYSTEMS

The open-source SIMONSTRATOR.KOM (B. Richerzhagen et al. 2015) simulation platform provides several models for wireless communication, message transport, node mobility, and energy consumption relying on the network simulator PEERFACTSIM.KOM (Stingl, Gross, et al. 2011; Stingl, B. Richerzhagen, et al. 2013). Furthermore, SIMONSTRATOR.KOM allows simulating a large number of heterogeneous nodes with different properties at the same time. It can also use map data from OpenStreetMap[2] (OSM) to simulate, e.g., urban environments where node movement can be restricted to walkways, bike lanes, or roads, respectively.

This simulation environment constitutes a well-suited basis which we extended towards a fully fledged simulation platform for Unmanned Aerial Systems[3]. The added extensions and their interactions are shown in Figure 4. The PEERFACTSIM.KOM simulator is extended by required UAV components such as batteries, actuators, and controllable movement models, which eventually form the entire simulated vehicle. Besides the possibility to simulate UAVs, we also added a base station that provides necessary infrastructure like battery recharging and landing pads for the UAVs. On the application layer at the SIMONSTRATOR.KOM platform, mission planning, and coordination were added to the base stations and controlling strategy execution to the UAVs. In the following, we discuss the extensions in detail.

Energy Consumption and Battery Recharging

PEERFACTSIM.KOM already provides a battery model including the power consumption of device components such as displays, communication interfaces like WiFi, or miscellaneous equipment like GNSS sensors. Power consumption is adjustable for each device, respectively, using voltage and power draw in different states, for example, *TRANSMIT* or *RECEIVE* in case of a WiFi chip. Batteries are defined by their capacity in Joule. We added a new component modeling the actuators required for the UAV propulsion, where the power consumption is regulated continuously between a minimum and a maximum parameter. This is necessary to abstract situations such as constant flight speed and altitude, where only friction has to be compensated, or ascent, where actuators require more power to accelerate the UAV. Parameter settings for power consumption depend on the actual UAVs—or more specifically the used actuators—that are modeled, as mentioned by Dietrich et al. 2017b.

Due to the limited battery capacity, a long-term UAV deployment requires the possibility to recharge or to entirely replace a drained battery. We include a charger model to the simulator, which continuously recharges a UAV's battery by a fixed amount of Joule per second, modeling, for example, a contactless induction charger as proposed by Hu et al. 2008. However, continuous recharging is not the most efficient solution regarding vehicle utilization due to the long downtimes during the recharge process (Erdelj et al. 2017). We, therefore, added another model that

[2]www.openstreetmap.org

[3]The source code and simulation environment is available online: https://dev.kom.e-technik.tu-darmstadt.de

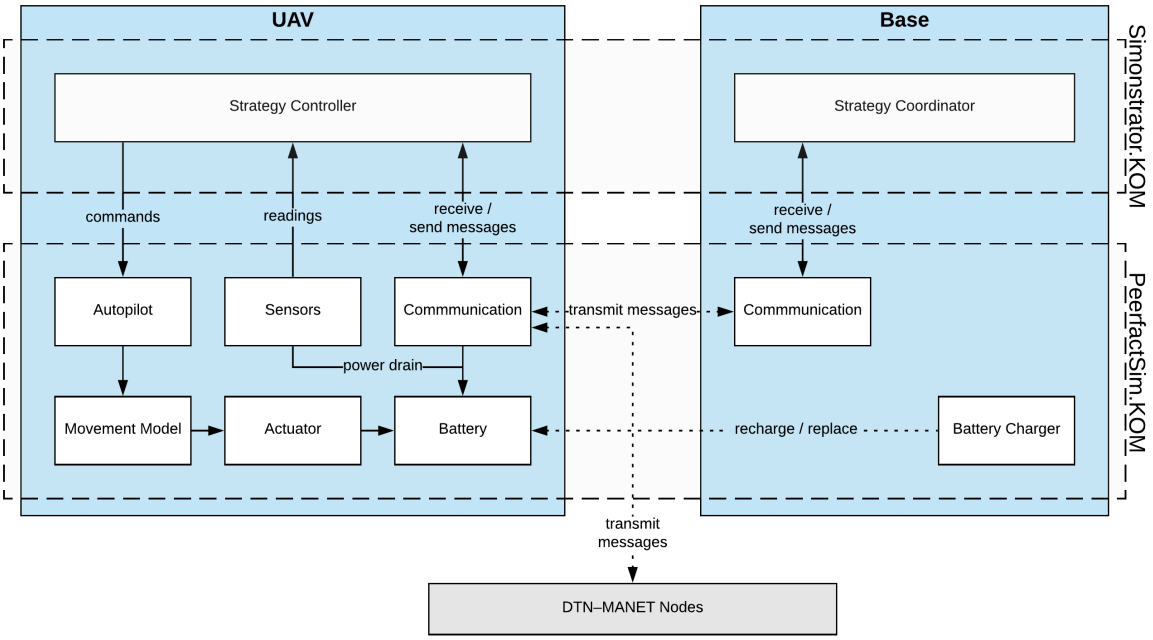


Figure 4. Overview of system components for UAVs and base stations comprising the UAS in the simulation platform, with their respective location in SIMONSTRATOR.KOM and PEERFACTSIM.KOM architecture. Dependencies between components are indicated by lines and arrows, dotted lines show non-permanent connections like message transfer over the network or during the battery recharging process.

is emulating manual or automated battery replacement. The default time to replace the entire battery is set to 60 seconds, based on the results in Fujii et al. 2013 and Ure et al. 2015, but can be customized if required. As in a real deployment, chargers are part of base stations.

UAV Autopilot and Movement Model

Available models for node movement included simple approaches like random walk or random waypoint, but also more sophisticated models like social movement between attraction points in an urban environment (N. Richerzhagen et al. 2017). Realistically, the application cannot directly control the movement of a user. Thus, the movement models in the simulator are fully separated from the application layer. However, this separation is not given in the case of a UAV, since vehicle movement is controllable by an autopilot. We therefore added a controllable UAV movement model.

In our platform, we premise all UAVs to be capable of fully autonomous flight, performed by an autopilot. All autopilots offer a generic interface to the application layer, through which commands like *'move to coordinate x'* or *'change altitude'* can be issued. The autopilot then autonomously executes the commands within the capabilities of the UAV. These capabilities are specified by a UAV movement model. We first implemented a model for multicopter UAVs due to their straightforward and precise maneuverability, their ability to hover, and because they constitute the majority of commercially available UAVs (Namuduri et al. 2018). The models define basic procedures like take-off, touch-down, ascent, and descent, but also flight maneuvers such as hovering, circling a position, or route traversal. Furthermore, variables like minimum and maximum speed, reachable flight altitudes, and movement limitations, in general, are defined therein.

Communication

Devices for wireless communication such as Bluetooth and WiFi are already implemented in PEERFACTSIM.KOM. Available communication devices can be used for various purposes, such as for control and coordination messages between UAVs and the Base Station, for communication between multiple UAVs, and the communication between UAVs and the DTN-MANET nodes on the ground. The modular setup of communication devices in PEERFACTSIM.KOM allows using multiple, possibly different devices in parallel, which enables the full separation of channels, if necessary. For example, we can use a WiFi device on the UAVs to exchange messages with the nodes on the ground in accordance with the employed DTN-MANET protocol. Another WiFi device then is used

for UAV-to-UAV communication allowing decentralized coordination of the UAVs or to build up a distinct relay network (Morgenthaler et al. 2012). A long-range control channel may also be deployed by a third device, e.g., using LoRa[4].

System Application

These extensions on the simulator layer now provide the capabilities which are necessary to develop and evaluate a mobile aerial system in SIMONSTRATOR.KOM. We utilize the interfaces given by the simulator to define a modular system design that is independent of the simulated UAV and thus of its hardware. On each UAV, a Strategy Controller is responsible to execute a given strategy and fulfill the states mission objectives. Controlling the autopilot and using communication devices is available through provided interfaces. Sensor readings like the vehicle's location or battery levels can also be obtained and may be included in the strategy execution.

Base stations, in contrast, run a Strategy Coordinator in the application layer. It is responsible for managing all strategies currently in execution. Several strategies can run in parallel, each of them with its distinct set of UAVs. Executed strategies on the base station are responsible for the coordination and control of their respective UAVs. Hence, each strategy used in the application requires a definition for UAVs and another for the base station.

SUPPORT STRATEGIES FOR POST-DISASTER COMMUNICATION NETWORKS

As shown in our previous work Álvarez et al. 2018, the typical human behavior of forming groups and loitering around important locations, in the field test three different villages, leads to heavily intermittent communication islands in the DTN-MANET. Conventional dissemination methods that rely on occasional and uncontrollable encounters of nodes, therefore, cannot provide sufficient communication performance. Especially for high priority messages such as emergency calls, long propagation delays are unacceptable (Álvarez et al. 2018; Baumgärtner et al. 2017).

Small, commercially available UAVs could be used as controllable communication bridges between separated islands. The simulation platform for Unmanned Aerial Systems presented in this paper empowers the assessment of the feasibility and the impact of such a deployment. System behavior is defined by strategies which can be customized and exchanged, allowing to evaluate the advantages and disadvantages of different strategies. Furthermore, adapting parameter settings in the simulation enables the assessment of each strategy with different UAVs or under varying environmental influences. Thus, this platform provides an extensive scope of potential systems that can be developed and evaluated.

As a proof-of-concept, we designed a UAS for the support of civilian-centric post-disaster emergency communication networks. Two basic strategies with distinct features and requirements were implemented to show the wide range of possible UAV deployments (c.f. Figure 5), namely a full-coverage relay mesh requiring large numbers of UAVs (Morgenthaler et al. 2012) and a message ferry approach with only a few UAVs moving between fixed locations (Zhao et al. 2004). Both strategies use multicopter UAVs and are evaluated for their impact on a ground-based network using the DTN-MANET protocol HyperGossip (Khelil et al. 2007).

The idea of the relay mesh strategy is to provide a provisional communication infrastructure to an affected area. Ground devices communicate with the UAVs which act as relay nodes within the dedicated aerial relay network (Morgenthaler et al. 2012). UAVs collect messages and further disseminate them through the relay network, other UAVs then distribute the messages down to the DTN-MANET nodes. The advantage of this strategy is the complete coverage of the affected area, with short delivery delays and also exhaustive message distribution. However, the large amount of required UAVs is a considerable drawback. To provide full-coverage service in a 4 km^2 area with an approximated 75 meters transmission range for the WiFi communication given by the simulator, the distance between UAVs should not exceed 150 meters. Thus, at least 178 UAVs are required to staff each location in a quadratic equidistant relay mesh. For continuous service, however, additional UAVs are required as replacements, otherwise vacancies in the mesh will have a negative impact on the performance. By executing simulations with the graphical representation, as shown in Figure 6, we figured out that 200 UAVs are sufficient to provide continuous service in the complete area without vacancies in the mesh.

The message ferry approach (Zhao et al. 2004) utilizes UAVs as controllable and highly mobile nodes to amplify the communication performance amongst intermittent communication islands forming around important locations. On each of the islands, UAVs hover for some time—in our simulation set to 30 seconds—while collecting and distributing DTN-MANET messages. After that, they move to the next island in the sequence, where the procedure is repeated. UAVs are therefore simple data carriers, but due to their high velocity and independence of roads they

[4]https://lora-alliance.org/

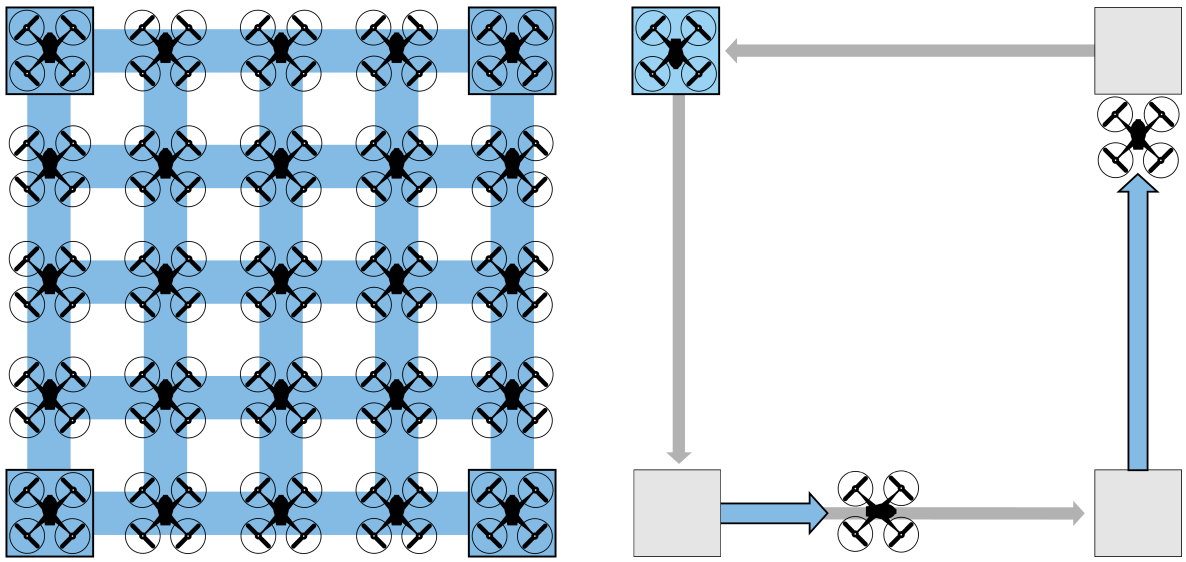


Figure 5. Visualization of two basic, but very different support strategies. Left: Full coverage mesh with equidistant relay node positioning, high requirements on the number of available UAVs. Right: Message ferry strategy, few UAVs can carry data between communication islands but it requires physical transport of each message.

can distribute their messages significantly better than achievable by foot or by car. The advantage of this strategy is a faster message dissemination compared to the conventional DTN-MANET store-carry-forward principle. Furthermore, the strategy can also be executed with only a single UAV, but we expect performance to increase with more UAVs. The drawbacks are a longer and less thorough message dissemination in comparison to the relaying mesh, and most significantly the necessity to know the location of communication islands in advance. In this implementation, a single shortest route connecting all islands and the base station is calculated. Locations are approached sequentially in the same order by each UAV. Performance increases by using multiple or different routes are open for further research.

Both strategies are evaluated with the parameters summarized in Table 1. A 2 km x 2 km inner-city area is simulated for 5 hours with 100 ground nodes moving as pedestrians on walkways. Nodes choose their targets from important locations such as market places, parks, or hospitals. On arrival, nodes stay at the location for a certain pause time between 5 minutes and 5 hours. These pause times model human behavior like social grouping and tasks that have to be executed at these locations, as shown in the field test (Álvarez et al. 2018). A workload generator creates a broadcast message to all nodes every 10 seconds on a randomly chosen node. After a defined message lifetime (time-to-live, TTL) of 30 minutes, messages are discarded and removed from all nodes. As evaluation metrics, we measure the recall, as the percentage of nodes that have received a message within the TTL, and delivery delay, representing the time it took to reach all nodes. Evaluation results are shown in Figure 8 for recall and delivery delay, comparing the DTN-MANET without support against the mesh and the ferry strategy, respectively. Simulations were repeated ten times with varying random seeds. Boxes indicate the 25th and 75th percentile with the median value as bold dash and whiskers indicate the 2.5th and 97.5th percentile. The horizontal axis shows the different pause time, ranging from 5 to 60 minutes minimum pause time, and also without movement between islands.

It can be observed that the unsupported DTN-MANET is behaving as expected. With less inter-island movement, recall drops due to fewer encounters with other nodes, to a point when messages are only distributed within an island when there is no node movement. However, even with 30 minutes TTL and node movement, messages are distributed to 4 of 5 islands at best. Furthermore, more than 50 percent of delivered messages require more than 9 minutes, and 25 percent need more than 20 minutes for their dissemination. As seen in the setting without movement, message dissemination within a communication island is very fast. Measured values show a delivery delay of a few milliseconds on average.

The mesh strategy achieves a perfect recall and very short delivery delays. In some cases, nevertheless, dissemination can take a few minutes to reach every single node on the ground. This results due to packet collisions during the message propagation to or within the DTN-MANET, since relay nodes only push new messages down to the ground nodes once. In accordance with the HyperGossip protocol (Khelil et al. 2007), messages are stored and only forwarded if a previously unknown node is met. Thus, the forwarding is only triggered by nodes moving to a new communication island.

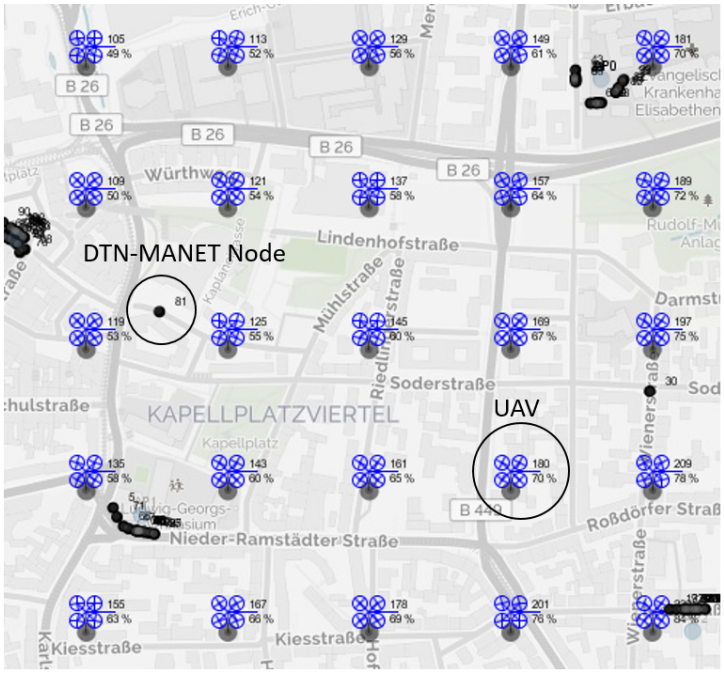


Figure 6. UAVs form a relay mesh in an urban environment. The graphical representation of SIMONSTRATOR.KOM shows UAVs hovering above the map and DTN-MANET nodes on the ground. Nodes use pedestrian walkways when moving or gather around important locations. UAVs are visualized with their current battery levels.

As shown in Figure 7, message ferries follow a predefined path. Since the physical movement of the messages is required for the dissemination, there are significant delivery delays in comparison to the mesh strategy. However, delays are much smaller than for the pure unsupported DTN-MANET environment, most of them in the range of 5 to 10 minutes. With node movement, delays are considerably higher due to the lack of node encounters while they move between islands. This also has a small negative influence on recall, if the message lifetime is exceeded while a node moves. As a consequence, the message ferry approach performs best when the ground network topology is not changing and every node is part of a communication island.

In conclusion, the relay mesh strategy outperforms the ferry strategy in both recall and delivery delay. However, the mesh strategy is highly inefficient in environments with communication islands, due to the large sparsely frequented areas in between where no UAVs are needed for communication support. As the number of UAVs influences both the complete system costs in acquisition and maintenance, the amount of required infrastructure such as landing pads and battery chargers, as well as the size of necessary power sources, an efficient utilization of the available UAVs is key. The message ferry strategy on the other hand requires significantly less UAVs and specifically targets

Parameter	Setting
Simulated Time	5 hours
Simulated Area	2 km x 2 km
Number of Islands	5
Number of Nodes	100
Node Movement	1 – 2 $\frac{m}{s}$
Pause Time	5 – 300 minutes
Message Lifetime (TTL)	30 minutes
Message Generation	1 broadcast every 10 seconds
Mesh Strategy	200 UAVs, 150 meters mesh distance
Ferry Strategy	10 UAVs, 15 $\frac{m}{s}$ speed
UAV Flight Time	20 – 25 minutes
UAV Flight Altitude	30 meters
UAV Battery Replacement	60 seconds

Table 1. Simulation parameter settings for the urban scenario.

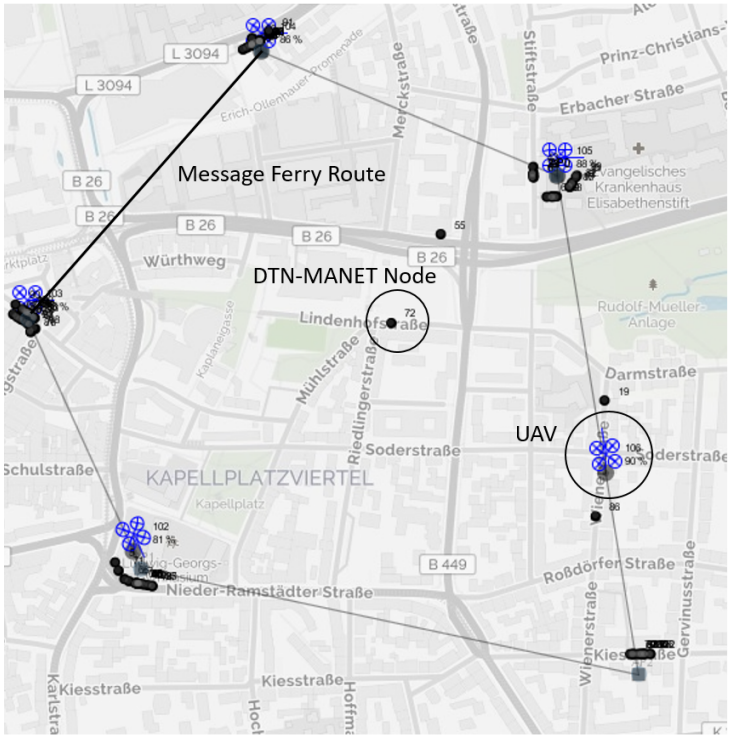


Figure 7. Message ferry UAVs move between five communication islands. They hover above each location while exchanging messages with the DTN-MANET nodes on the ground, before moving to the next. UAVs only visit statically defined islands, thus, nodes out of transmission range cannot be reached.

the dissemination between communication islands. However, for a practical real-world application, the system must be configured such that it performs well in the considered scenario by using the available resources in a meaningful way. We therefore analyze the impact of the number of available UAVs on the ferry strategy. Therefore, we map the environmental characteristics of the field test (Álvarez et al. 2018) into the simulation platform as displayed in the visualization in Figure 9. This contains the underlying map of the area, the number of participants and the movement patterns between the three different villages.

With normal movement speed, it takes a node approximately 12 minutes to walk from Village B to Village C and approximately 50 to 70 minutes to walk from Village C to Village A. In the field test area, there was no direct walking path connection between Village B and Village A. We use 10 different seeds for the simulation to alternate the movement and the workload generator. Available UAVs were varied between 0 and 20 and a TTL of 10, 30, and 60 minutes was considered, respectively. Although a 10 minutes TTL is too short for common DTN-MANETs, results give insight into the possibilities of quick dissemination regarding emergency calls enabled by UAV support.

As indicated by the straight lines in Figure 9, UAVs fly directly between villages. The flight duration between Village B and Village C is 45 seconds, between B and A 4.4 minutes, and 4.1 minutes between A and C, respectively. UAVs need 18 seconds between the UAS Base Station and Village C, and furthermore, will hover over each village for a dissemination time of 30 seconds. Because the combination of flight and hover time will consume more than 53% of the full battery capacity, a UAV will not be able to complete more than one iteration. Thus, it will return to the base station after visiting Village C, B, and A consecutively, for a 60-second battery exchange phase. The total time it will take a UAV to complete one full iteration including dissemination and battery exchange, therefore, is around 12 minutes.

Figure 10 depicts the results for recall and delivery delay, starting with no UAV support up to 10 message ferry UAVs. Boxes indicate the 25th and 75th percentile with the median value as bold dash and whiskers indicate the 2.5th and 97.5th percentile. The results for 11 up to 20 UAVs are not displayed in the figure, because only minor changes in the delivery delay are perceived.

With no UAV support and a TTL of 10 minutes, messages only spread in the village where the message is generated, resulting in approximately a third of the nodes receiving the message with a very low delivery delay. With a TTL of 30 and 60 minutes, the movement of the nodes is sufficient to deliver messages between the different villages, resulting in a median recall value of 0.7 and 0.8, respectively. However, Figure 10 shows that one or two UAVs

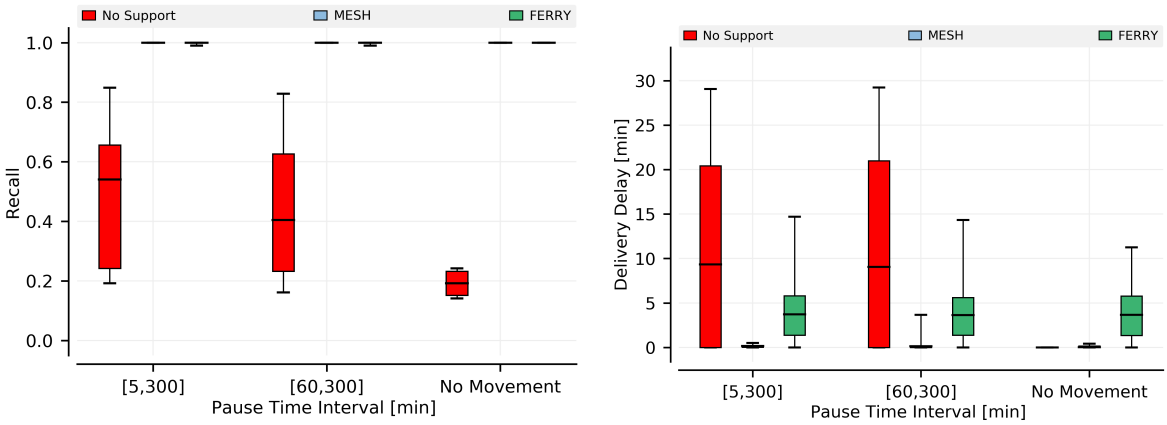


Figure 8. Recall (left) and delivery delay (right), comparing the DTN-MANET without support to the relay mesh strategy and the message ferry strategy, respectively.

Figure 9. Simulation of the field test environment in SIMONSTRATOR.KOM. Similar to the behavior perceived in (Álvarez et al. 2018), most nodes group within the three villages. Only a few nodes move between the villages using the roads connecting Village A and C (approximately 5 km) and Village B and C (approximately 1 km). The UAV Base Station is located near Village C. Straight lines indicate the route UAVs take, reducing the distance between Village B and C to around 660 meters as well as the distance between Village A and C to under 3.7 km. The full route including the distance to the UAS Base Station is around 8.6 km long, one UAV takes around 12 minutes to complete one full iteration, including the time for dissemination and battery exchange.

increases the recall significantly, regardless of the applied TTL. As this requires the physical transport of messages transmitted to other communication islands, the perceived delivery delay also increases, best seen in the results for 10 minute TTL. The utilization of additional UAVs further increases the recall while reducing the delivery delay. However, due to the fixed route between villages and the base station, which the UAVs traverse, more UAVs will only result in decreased intervals between visits of UAVs in the villages. The route traversal time stays the same, nevertheless, which leads to a saturation of the system. Thus, no more significant changes in both recall and delivery delay are perceived. Furthermore, the optimal recall of 1.0 cannot be reached for a TTL of 10 or 30 minutes due to nodes moving in between communication islands. Messages that are generated during the transit can expire before the node reaches an island, with increasing negative influence for smaller TTL settings. This problem cannot be solved by the used message ferry strategy, e.g., by increasing the used UAVs, but requires more complex strategies that are left open for further research.

Evaluation results like this can be used to design and optimize a Unmanned Aerial Communication Support System for specific scenarios. Regarding the characteristic of the supported DTN-MANET, required strategy properties can be determined. For example, when supporting a DTN-MANET with a TTL of 60 minutes 2 UAVs are sufficient to achieve optimal recall in our scenario. Utilizing additional UAVs result in lower delivery delay, however, more than 7 UAVs do not yield significant improvements, reaching a delivery delay of less than 10 minutes for approximately 75% of the messages.

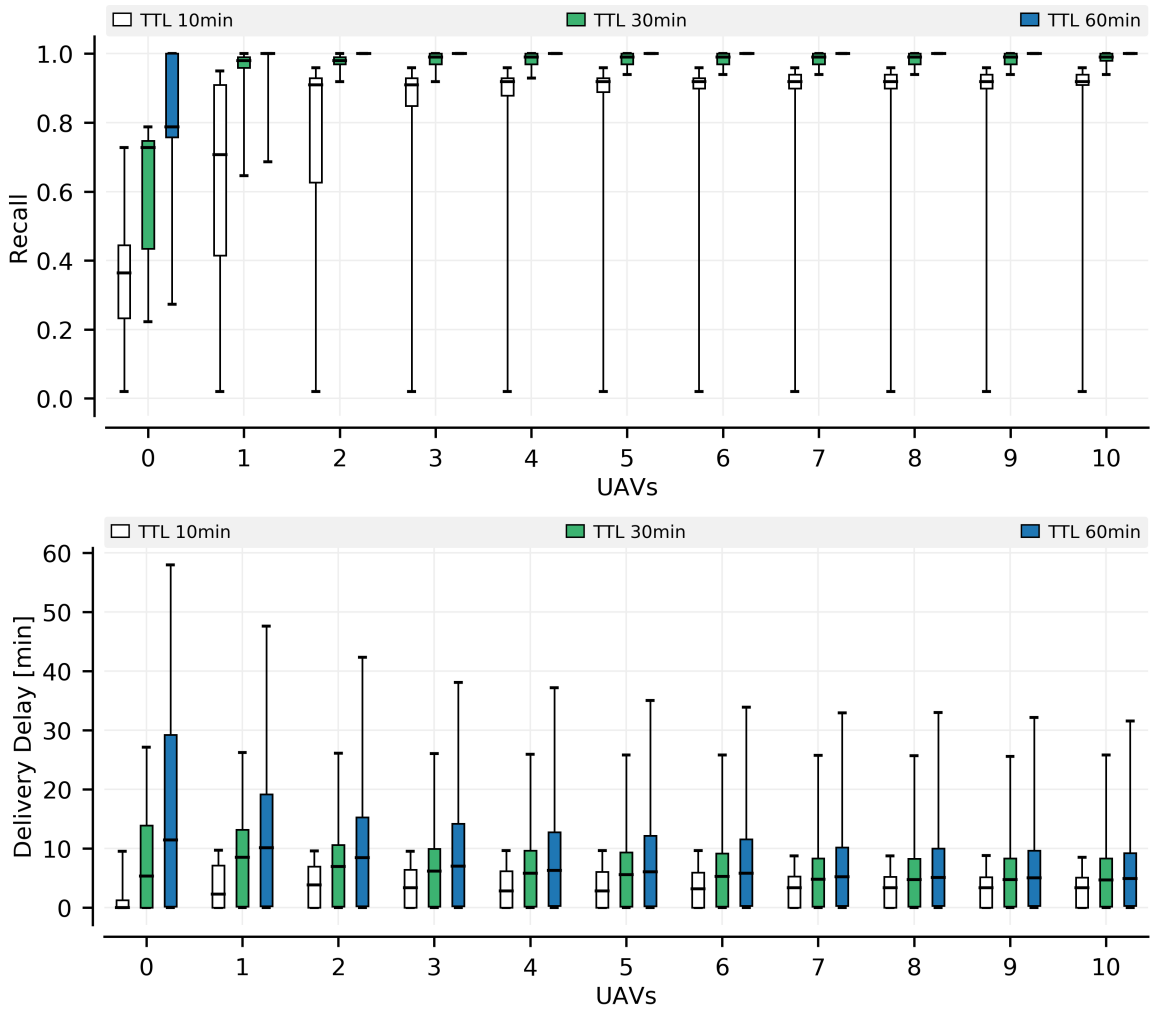


Figure 10. Recall and delivery delay variance shown for increasing numbers of UAVs. The TTL was set to 10, 30 and 60 minutes, respectively. As indicated, a few UAVs already significantly increase the communication performance, especially with longer TTL. The setting '0 UAVs' shows the unsupported DTN-MANET performance.

CONCLUSION, DISCUSSION & FUTURE WORK

In this paper, we motivated the need for efficient UAV-based communication bridges between DTN-MANET communication islands in post-disaster scenarios based on our findings from a large-scale field test (Álvarez et al. 2018) and other related work. However, to assess the performance of individual strategies for the deployment and coordination of UAVs, it is not feasible to repeat such tests on a regular basis. To address this issue, we proposed a discrete event-based simulation platform for Unmanned Aerial Systems (UASes) in this work, combining models for an individual UAV's behavior and its communication abilities with a fully-fledged network simulator for DTN-MANETs for the first time.

To showcase the capabilities of our platform, we discussed two representative strategies for large-scale UAV support of a DTN-MANET in post-disaster scenarios. We evaluated both strategies in an urban environment, highlighting their individual cost vs. performance profiles. Additionally, we provided an in-depth discussion w.r.t. the meaningful utilization of resources by modeling the conducted field test in our simulation platform and evaluating the message ferry strategy with different amounts of UAVs. Our evaluation successfully demonstrates the ability of our proposed platform to assess the performance of UASes and the determination of critical strategy properties in combination with various DTN-MANET scenarios.

For future work we plan to integrate additional models, such as channel models for long-range communication (e.g., LoRa) and other UAV types (e.g., fixed-winged UAVs) into our platform. Furthermore, we want to assess the ability of UAV support strategies to adapt to changes in the DTN-MANET caused by human behavior and changing communication demands (Klinsompus and Nupairoj 2015) and message type priorities (Lieser, N. Richerzhagen, Luser, et al. 2019) over the course of the disaster. Therefore, monitoring techniques in a resource-constrained environment are of great interest.

ACKNOWLEDGMENT

This work has been co-funded by the following projects: the LOEWE initiative (Hesse, Germany) within the NICER[5] and the Natur 4.0 project, the German Federal Ministry of Education and Research (BMBF) within the SMARTER[6] project.

REFERENCES

Al-Akkad, A., Ramirez, L., Boden, A., Randall, D., and Zimmermann, A. (2014). "Help beacons: Design and evaluation of an ad-hoc lightweight sos system for smartphones". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 1485–1494.

Álvarez, F., Almon, L., Lieser, P., Meuser, T., Dylla, Y., Richerzhagen, B., Hollick, M., and Steinmetz, R. (2018). "Conducting a Large-scale Field Test of a Smartphone-based Communication Network for Emergency Response". In: *Proceedings of the 13th Workshop on Challenged Networks*. ACM, pp. 3–10.

Baumgärtner, L., Kohlbrecher, S., Euler, J., Ritter, T., Stute, M., Meurisch, C., Mühlhäuser, M., Hollick, M., Stryk, O. von, and Freisleben, B. (2017). "Emergency Communication in Challenged Environments via Unmanned Ground and Aerial Vehicles". In: *Global Humanitarian Technology Conference (GHTC)*. IEEE.

Belbachir, A., Escareno, J., Rubio, E., and Sossa, H. (2015). "Preliminary results on UAV-based forest fire localization based on decisional navigation". In: *Workshop on Research, Education and Development of Unmanned Aerial Systems (RED-UAS)*. IEEE, pp. 377–382.

Daniel, K., Dusza, B., Lewandowski, A., and Wietfeld, C. (2009). "AirShield: A system-of-systems MUAV remote sensing architecture for disaster response". In: *3rd Annual Systems conference*. IEEE, pp. 196–200.

Dietrich, T., Krug, S., and Zimmermann, A. (2017a). "A discrete event simulation and evaluation framework for multi UAV system maintenance processes". In: *Systems Engineering Symposium (ISSE)*. IEEE, pp. 1–6.

Dietrich, T., Krug, S., and Zimmermann, A. (2017b). "An empirical study on generic multicopter energy consumption profiles". In: *Systems Conference (SysCon), 2017 Annual IEEE International*. IEEE, pp. 1–6.

Erdelj, M., Saif, O., Natalizio, E., and Fantoni, I. (2017). "UAVs that fly forever: Uninterrupted structural inspection through automatic UAV replacement". In: Elsevier.

Fujii, K., Higuchi, K., and Rekimoto, J. (2013). "Endless flyer: a continuous flying drone with automatic battery replacement". In: *Ubiquitous Intelligence and Computing, 2013 IEEE 10th International Conference on and 10th International Conference on Autonomic and Trusted Computing (UIC/ATC)*. IEEE, pp. 216–223.

Gardner-Stephen, P., Challans, R., Lakeman, J., Bettison, A., Gardner-Stephen, D., and Lloyd, M. (2013). "The serval mesh: A platform for resilient communications in disaster & crisis". In: *Global Humanitarian Technology Conference (GHTC)*. IEEE, pp. 162–166.

Gardner-Stephen, P., Challans, R., Lakeman, J., Bettison, A., Lieser, P., Steinmetz, R., Alvarez, F., and Lloyd, M. (2017). "Productizing humanitarian telecommunications research: A case study of the serval mesh extender". In: *Global Humanitarian Technology Conference (GHTC), 2017 IEEE*. IEEE, pp. 1–10.

George, S. M., Zhou, W., Chenji, H., Won, M., Lee, Y. O., Pazarloglou, A., Stoleru, R., and Barooah, P. (2010). "DistressNet: a wireless ad hoc and sensor network architecture for situation management in disaster response". In: *IEEE Communications Magazine* 48.3.

Hossmann, T., Legendre, F., Carta, P., Gunningberg, P., and Rohner, C. (2011). "Twitter in disaster mode: Opportunistic communication and distribution of sensor data in emergencies". In: *Proceedings of the 3rd Extreme Conference on Communication: The Amazon Expedition*. ACM, p. 1.

Hu, A. P., Liu, C., and Li, H. L. (2008). "A novel contactless battery charging system for soccer playing robot". In: *Mechatronics and Machine Vision in Practice, 2008. M2VIP 2008. 15th International Conference on*. IEEE, pp. 646–650.

Khelil, A., Marrón, P. J., Becker, C., and Rothermel, K. (2007). "Hypergossiping: A generalized broadcast strategy for mobile ad hoc networks". In: *Ad Hoc Networks* 5.5, pp. 531–546.

Klinsompus, P. and Nupairoj, N. (2015). "Critical message scheduling for disaster response and recovery phases". In: *Information and Communication Technology Convergence (ICTC)*. IEEE, pp. 65–70.

[5]Networked Infrastructureless Cooperation for Emergency Response
[6]Smartphone-based Communication Networks for Emergency Response

Li, X., Guo, D., Yin, H., and Wei, G. (2015). "Drone-assisted public safety wireless broadband network". In: *Wireless Communications and Networking Conference Workshops (WCNCW)*. IEEE, pp. 323–328.

Lieser, P., Alhamoud, A., Nima, H., Richerzhagen, B., Huhle, S., Böhnstedt, D., and Steinmetz, R. (2018). "Situation Detection based on Activity Recognition in Disaster Scenarios". In: *Proceedings of the International Conference on Information Systems for Crisis Response and Management (ISCRAM)*.

Lieser, P., Alvarez, F., Gardner-Stephen, P., Hollick, M., and Boehnstedt, D. (2017). "Architecture for Responsive Emergency Communications Networks". In: *Global Humanitarian Technology Conference (GHTC). IEEE*.

Lieser, P., Richerzhagen, N., Feuerbach, T., Meuser, T., Rocherzhagen, B., and Steinmetz, R. (2018). "Collaborative Decentralized Resource Reservation for Emergency Communication Networks". In: *43rd IEEE Conference on Local Computer Networks (LCN)*.

Lieser, P., Richerzhagen, N., Feuerbach, T., Nobach, L., Böhnstedt, D., and Steinmetz, R. (2017). "Take it or Leave it: Decentralized Resource Allocation in Mobile Networks". In: *42nd IEEE Conference on Local Computer Networks (LCN)*.

Lieser, P., Richerzhagen, N., Luser, S., Richerzhagen, B., and Steinmetz, R. (2019). "Understanding the Impact of Message Prioritization in Post-Disaster Ad Hoc Networks". In: *Proc. International Conference on Networked Systems (NetSys)*. ACM.

Luqman, F., Sun, F.-T., Cheng, H.-T., Buthpitiya, S., and Griss, M. (2011). "Prioritizing data in emergency response based on context, message content and role". In: *Proceedings of the 1st International Conference on Wireless Technologies for Humanitarian Relief*. ACM, pp. 63–69.

Meurisch, C., Wullkotte, S., Niemczyk, S., Kohnhäuser, F., Mühlhäuser, M., et al. (2017). "NICER911: Ad-hoc Communication and Emergency Services Using Networking Smartphones and Wireless Home Routers". In: *Proceedings of the 18th ACM International Symposium on Mobile Ad Hoc Networking and Computing*. ACM, p. 33.

Mokryn, O., Karmi, D., Elkayam, A., and Teller, T. (2012). "Help Me: Opportunistic smart rescue application and system". In: *Ad Hoc Networking Workshop (Med-Hoc-Net), 2012 The 11th Annual Mediterranean*. IEEE, pp. 98–105.

Morgenthaler, S., Braun, T., Zhao, Z., Staub, T., and Anwander, M. (2012). "UAVNet: A mobile wireless mesh network using unmanned aerial vehicles". In: *Globecom Workshops (GC Wkshps), 2012 IEEE*. IEEE, pp. 1603–1608.

Mori, A., Okada, H., Kobayashi, K., Katayama, M., and Mase, K. (2015). "Construction of a node-combined wireless network for large-scale disasters". In: *Consumer Communications and Networking Conference (CCNC), 2015 12th Annual IEEE*. IEEE, pp. 219–224.

Namuduri, K., Chaumette, S., Kim, J. H., and Sterbenz, J. P. (2018). *UAV Networks and Communications*. Cambridge University Press.

Ranghieri, F. and Ishiwatari, M. (2014). *Learning from Megadisasters: Lessons from the Great East Japan Earthquake*. Washington, DC: World Bank.

Rémy, G., Senouci, S.-M., Jan, F., and Gourhant, Y. (2013). "SAR Drones: Drones for Advanced Search and Rescue Mission". In: *Journées Nationales des Communications dans les Transports*.

Richerzhagen, B., Stingl, D., Rückert, J., and Steinmetz, R. (2015). "Simonstrator: Simulation and Prototyping Platform for Distributed Mobile Applications". In: *EAI International Conference on Simulation Tools and Techniques (SIMUTOOLS)*, pp. 1–6.

Richerzhagen, N., Richerzhagen, B., Stingl, D., and Steinmetz, R. (2017). "The human factor: A simulation environment for networked mobile social applications". In: *Networked Systems (NetSys)*. IEEE, pp. 1–8.

Rohde, S., Putzke, M., and Wietfeld, C. (2013). "Ad hoc self-healing of OFDMA networks using UAV-based relays". In: *Ad Hoc Networks* 11.7, pp. 1893–1906.

Scherer, J., Yahyanejad, S., Hayat, S., Yanmaz, E., Andre, T., Khan, A., Vukadinovic, V., Bettstetter, C., Hellwagner, H., and Rinner, B. (2015). "An autonomous multi-UAV system for Search and Rescue". In: *Proceedings of the First Workshop on Micro Aerial Vehicle Networks, Systems, and Applications for Civilian Use*. ACM, pp. 33–38.

Stingl, D., Gross, C., Rückert, J., Nobach, L., Kovacevic, A., and Steinmetz, R. (2011). "Peerfactsim.KOM: A simulation framework for peer-to-peer systems". In: *Proc. High Performance Computing and Simulation (HPCS)*. IEEE, pp. 577–584.

Stingl, D., Richerzhagen, B., Zöllner, F., Gross, C., and Steinmetz, R. (2013). "PeerfactSim. KOM: Take it back to the Streets". In: *Proc. High Performance Computing and Simulation (HPCS)*. IEEE, pp. 80–86.

Uchida, N., Kawamura, N., Takahata, K., Shibata, Y., and Shiratori, N. (2013). "Proposal of data triage methods for disaster information network system based on delay tolerant networking". In: *Broadband and Wireless Computing, Communication and Applications (BWCCA), 2013 Eighth International Conference on*. IEEE, pp. 15–21.

Ure, N. K., Chowdhary, G., Toksoz, T., How, J. P., Vavrina, M. A., and Vian, J. (2015). "An automated battery management system to enable persistent missions with multiple aerial vehicles". In: *IEEE/ASME Transactions on Mechatronics* 20.1, pp. 275–286.

Zhao, W., Ammar, M., and Zegura, E. (2004). "A message ferrying approach for data delivery in sparse mobile ad hoc networks". In: *Proceedings of the 5th ACM international symposium on Mobile ad hoc networking and computing*. ACM, pp. 187–198.

Understanding the Main Themes Towards a Visual Analytics Based Model for Crisis Management Decision-Making

Flavio Dusse
Federal University of Bahia
dussebr@dcc.ufba.br

Renato Novais
Federal Institute of Bahia
renato@ifba.edu.br

Manoel Mendonça
Federal University of Bahia
manoel.mendonca@ufba.br

ABSTRACT

Crisis Management (CM) refers to the ability to deal with crisis tasks in different phases and iterations. People working in a crisis are generally under stress to make the right decision at the right time. They have to process large amounts of data and to assimilate the received information in an intuitive and visual way. Visual Analytics (VA) is potentially useful to analyze and understand the huge amount of data in several areas including in a crisis. We designed a survey protocol to understand which themes influence visualizations to support CM. In previous work, we carried out systematic mapping studies, analysis of official documents, ethnographic studies, questionnaires during the large events held in Brazil in recent years. In this work, we interviewed eight CM specialists. We analyzed this data qualitatively with the coding technique. Then we evaluated the coding results with the focus group technique. With the results, we identified the relationships between the visual needs and other main themes of influence for CM. This thematic synthesis enabled us to build a draft model based on VA. We hope that, after future cycles of validations and improvements, the agencies that manage crises might use this model as a reference in their activities of knowledge production and decision-making.

Keywords

Crisis Management, Decision-Making, Visual Analytics, Computational Model.

INTRODUCTION

Crises have very complex and dynamic contexts where the response process should suit unforeseen situations without causing social harm or jeopardizing people's lives (ESRI, 2009). Examples of crises that greatly stimulated research interest in this area were the attacks of September 11, 2001 and Hurricane Katrina in 2005 both in the United States. More recently, the Hurricanes Harvey, Irma and Maria and a sequence of terrorist attacks in European cities, mass shootings in U.S. among others have reinforced the interest in this area. Crisis management (CM) refers to the ability to deal with crisis tasks in all their phases and iterations. In general, this is done by multiple government agencies, which do not work together routinely. These agencies usually use the doctrine of Command and Control (C2) to help in the coordination of activities (Turoff *et al*., 2004). C2 is the exercise of authority and direction by a properly designated commanding office over assigned resources in the accomplishment of a common goal (Builder *et al*., 1999).

CM varies because the context, events and information are never the same from one crisis to another. Each management task requires many different types of information about the incident from several sources (Turoff *et al*., 2004), such as information systems, external proprietary databases, resources in the field, internet of things sensors, social media and other open source media. Nowadays, C2s are equipped with breakthrough technologies, especially visual systems, such as the latest generation mobiles, tabletops, video walls and e-caves (Dusse *et al.,* 2016). This union of data sources and novel technologies provides C2 with huge amounts of information of great heterogeneity.

Decision making during a crisis requires having the right information, provided in the right way, to the right people, at the right time. While crisis managers working in a crisis are generally under stress, they have to make effective and agile decisions. Having reliable and up to date information is essential in order to help in the making of such decisions (Yates and Paquette, 2010). Crisis managers need to assimilate the received information in an intuitive way and the information needs to be adaptable in the context of the current crisis. In addition, if the information is not presented in effective ways, it can be hard to analyze it, or in the worst cases, it can be misinterpreted. Literature shows that suitable information visualization techniques improve the understanding of crisis information (Ciolkowski *et al*., 2003; Thom *et al*., 2012; Bosch *et al*., 2013).

Recently, researchers have been using Visual Analytics (VA) to support understanding in this subject (Andrienko *et al*., 2007; Tomaszewski and MacEachren, 2012; Chae *et al*., 2014; Marbouti *et al*., 2017). VA is potentially useful for analyzing and understanding the huge amount of information produced in a crisis (Keim *et al*., 2008). The benefits brought by VA to the analysis of crisis information also come along with certain challenges. These include: (1) how to map VA concepts with the countless variables of a crisis to support the managers in quickly identifying reliable information to make decisions; (2) whether researchers and practitioners are using VA techniques and tools effectively to tackle challenge 1; and, (3) how to enhance VA applications with minimal impact on current CM activities.

This paper extends our previous work (Dusse *et al.,* 2018), in which we presented the data collection from the literature through a systematic mapping study and *in-vivo* studies such as ethnographies and questionnaires. In this present work, we interviewed eight CM experienced professional from different C2 Centers. We crosschecked and analyzed this dataset qualitatively with formals techniques, coding and focus group in particular. These investigations are the initial part of a broader work that aims to define a computational model (see Figure 2). The main objective of this model is to use VA to enhance decision-making in CM. The research question of the broader work is "What aspects of visualizations are under-exploited in supporting decision-making in Crisis Management?" The data analysis reported in this paper is geared to answering this question.

We concluded in our previous work that the full potential of VA is not being applied in the state-of-the-art and state-of-the-practice of CM domain. In this present work, our data analysis identified the relevance of other themes, such as context, processes and human behavior, which are fundamental to decision-making. We concluded that researchers and practitioners do not pay due attention to key themes that they should be aware of and incorporate these into visualization tools. Thus, we used the results of this analysis to build a draft model based on VA. We hope that, after future cycles of validations and improvements, the agencies that manage crises might use this model as a reference in their activities of knowledge production and decision-making.

The rest of the paper is structured as follows. In the following section, we present the research design used in this work. We then describe the research execution and research evaluation, respectively. Then we discuss the lessons learned from this study and contributions achieved in this research. In closing, we suggest future research directions and we summarize our conclusions.

RESEARCH DESIGN

This work originated from three sources: i) the Brazil-European Union Rescuer Project (Villela *et al*., 2014), ii) a partnership that we have with the Public Security Secretariat of the State of Bahia (SSP-BA, in Portuguese) and, iii) the large events that occurred in recent years in Brazil, namely the 2014 Soccer World Cup and the 2016 Olympics Games. Below, we explain how this came about.

Background Information

From 2013 to 2016, we collaborated as a coworker with the Fraunhofer Project Center for Software and Systems Engineering at Federal University of Bahia (UFBA, in Portuguese)[1] and other Brazilian and European institutions in the scope of the RESCUER Project[2]. The RESCUER project involved developing a smart and interoperable computer platform for using crowdsourcing information mashed up with open data to support CM. In the scope of RESCUER, we decided to carry out a Systematic Mapping Study on how information visualization is applied in CM. We aimed to understand this area from literature reviews and visiting C2 centers in Brazil and Europe. Our goal was to find gaps and trends in the area.

Due to our partnership with SSP-BA, we had access to Intelligence and Operation Center (COI, in Portuguese)[3], which is a branch of the Secretariat. Located in the city of Salvador of the state of Bahia in Brazil, COI was

[1] http://www.fpc.ufba.br

[2] http://www.rescuer-project.org/

[3] http://www.ssp.ba.gov.br/2016/07/1237/Centro-de-Operacoes-inicia-nova-fase-da-Seguranca-Publica.html

created in 2016, taking the place of the Regional Command and Control Integrating Center in the State of Bahia (CICCR-BA, in Portuguese). Previously in 2011, the Federal Government of Brazil created the Extraordinary Secretary of Security for Large Events (SESGE, in Portuguese)[4], which is a branch of the Brazilian Ministry of Justice. The main purpose of SESGE is to coordinate the activities of the agencies involved in public security and civil defense during large events that have taken place in Brazil in recent years. In 2013, SESGE set up C2 centers in headquarter cities of large events. The old CICCR-BA was one of these. In these centers, multi-agencies work together in the coordination and sharing of resources (human, equipment, software).

In our previous work (Dusse *et al.,* 2018), we explored the CM activities in COI and visited two other Brazilian C2 centers and another in Europe: Regional Command and Control Integrating Center of the State of Rio de Janeiro (CICCR-RJ, in Portuguese), Command Integration Center of the City of Porto Alegre (CEIC, in Portuguese), Defense Zone of the Paris Police Prefecture (DZPPP, in French). Visiting C2 centers was very useful to compare and map similarities and inconsistencies among them. Practitioners in C2 environments work under strict time constraints, they work under a rigid schedule in scheme 24/7/365(6), i.e. without work stoppages. Hence, we planned to explore the best way the time spent of the visits. Thus, we carried out parallel researches: we made observations through ethnographic studies, we ran on-line questionnaires and we interviewed experienced crisis managers through a *survey protocol*. In this present paper, we report on the continuation of this previous work, specifically detailing with the interviews and the results obtained.

Survey Protocol (Interviews)

We conducted semi-structured interviews with eight crisis managers (domain specialists) from different places and countries: seven Brazilians and one French, from four different C2 centers, four specialists from COI, two specialists from CICCR-RJ, one specialists from CEIC and the last one from DZPPP. Since the interviewees had strict time constraints, the interviews took no more than 40 minutes on average.

We formalized the interviews in a survey protocol based on the rules in (Claes *et al*., 2000). The survey process consisted of six steps:

- **Step 1. Survey Definition:**

We determined the goal of the survey based on the objectives of this work. This is to investigate what the themes are and how they influence CM decision-making and how we can treat these themes using VA.

- **Step 2. Survey Design:**

We designed the survey defining interviewees, terms, materials, tasks, criteria, attributes, among others. We defined the techniques for data collection, the techniques for data analysis and the techniques to evaluate the results of the survey

We decided to conduct semi-structured interviews with at least three subjects (domain specialists). Semi-structured interviews are open-ended, more dynamic and allows for improvisation on the part of the interviewer and scope for a fuller exploration of the studied objects (Runeson and Host, 2009).

We decided to use only practitioners as subjects because they are familiar with the challenges of CM and face them every day in practice. We prepared two terms: term of consent and term of authorization of data publication. In the first one, the subject consents his/her participation with full knowledge of the nature of the procedures, with free will and without any coercion. The second term authorizes the authors to publish the collected data as they see fit, respecting individual data such as name and workplace.

Based on previous work (Dusse *et al*., 2018), we defined **three preliminary key factors** to guide the data collection and analysis. Table 1 describes these factors.

We formulated the questions and decided to do a pilot interview (Wohlin, 2000). The pilot was to make sure that the survey design was strict and reliable. The pilot led to an improved the survey protocol, if we detected problems or omissions in its procedures. We invited three domain specialists. The first interviewee was selected to perform the pilot study. After some improvements in the design, we carried out the other two interviews (subjects). At the end of the interviews, we asked the subjects to recommend other potential subjects; in total, we interviewed eight specialists. The survey design — which includes the preparation of the interview with the questions, the terms and other materials — is available on-line[5].

[4] http://www.copa2014.gov.br/pt-br/noticia/divulgado-o-plano-estrategico-de-seguranca-paracopa-do-mundo-de-2014

[5] https://wiki.dcc.ufba.br/pub/SoftVis/EMVis/file_3.pdf

Table 1: Preliminary Key Factors

Id	Key factors	Description
1	Raw Data	This refers to a set of values of variables collected from a source with no handling with which one obtains information to support factor 2.
2	Information Visualization	This factor defines the area that we are investigating to support factor 3.
3	Decision-making	This factor defines the main process that our study aims to support in the CM area.

We decided to use the *coding* technique to analyze the data. This is as an established technique in the literature to analyze qualitative datasets, such as transcriptions of interviews (Saldaña, 2015). It classifies the data in codes and clusters them into categories and major themes.

Lastly, we designed a *focus group* session to validate our analyses. We involved two researchers, one as moderator and the other as observer, and a group of specialists, some were interviewed (subjects) and others were not.

- **Step 3. Survey Implementation:**

We prepared the material necessary for the interview (subject invitation, room, audio recorder, pen, paper, etc.). In this step, we also did a pilot interview to refine the Protocol. It is important to highlight that this interview was not part of our analysis. As we mentioned in Step 2, we used it for the sole purpose of evaluating the strictness of the survey design. The pilot study allowed us to train the survey protocol and to improve the task description and goals.

- **Step 4. Survey Execution:**

In this step, we carried out the interviews. As mentioned, we carried out seven interviews (eight with the pilot) with practitioners, from four different C2 centers and two different countries. We recorded all the audios of the interviews. In the opening of the interview, as we designed, we asked the subjects to sign two terms: the consent form and authorization form. All subjects signed the consent form but two subjects signed the authorization form with reservations. They said that we could use what was spoken but without making any reference to the name of the interviewee nor where he/she works.

- **Step 5. Survey Analysis:**

Between the interviews and the analysis, we transcribed the interviews verbatim by listening and re-listening to the recording. We carried out the interviews in Portuguese, apart from one in English. Concerning this specific interview, after the transcription, we translated it to Portuguese. The transcripts of the seven interviews produced 127 pages of text.

We discarded one interview because the subject's answers were too superficial and, despite our attempts, he was not able to make the link between the preliminary key factors. We found that this subject did not have adequate knowledge to meet our goals defined in Step 1. We assumed that discarding this interview would not affect the results.

After the transcription of all the interviews, we sent emails to the subjects, attaching the transcribed text of their interview. In general, in an interview, people do not have much time to think about their answer. The purpose of the emails was to give them the opportunity to review their answers in their own time. As the interviewees work with strict time constraints, few returned our emails. Those who replied to our emails did not make relevant comments.

We also interacted with the subjects, days after the interviews, mainly with the ones that worked in COI. Whenever doubts arose regarding what some subject meant at some point in the interview, we looked for the subject and tried to clarify the doubts. These informal conversations with the specialists took no more than 2 minutes on average and they were repeated countless times. These informal conversations do not constitute the same scientific evidence as the survey protocol, for example, we did not plan nor record them. However, the data collected in these conversations were important for our study, mainly to mitigate some threats to the validity.

In a preliminary analysis, we found that according to the subjects managing a crisis is very complex. Many factors can influence the whole process, from the planning of the data collection to decision-making and its

operability. About the visual tools themselves, they outlined that tools are not prioritized, as they should be. They added that they need investment and research in this area. We conclude that in a multidisciplinary domain, such as CM, it is very hard to prioritize the factors that influence decision-making and it largely depends on the context and human aspects. You cannot neglect any factor, otherwise the response can be disastrous.

We analyzed the data in depth using a qualitative analysis technique. We identified specific segments of text to code, categorize and translate into major themes. As mentioned in Step 2 of the survey protocol, to analyze the data collected we decided to use the coding technique. Lastly, we evaluated our analysis findings using the focus group technique. We shall explain the data analysis in the following sections.

- **Step 6. Survey Packaging:**

The objective of the packaging step is to report the survey so that external parties can understand the survey scope and the results. We published the initial steps of our work (Dusse *et al.,* 2018). We also consider this text as part of the packaging.

It is important to cast light on the respondents' experiences. Their narrated experiences are very hard to gather from documents or observations. In the next sections, we shall explain in detail the research execution, i.e. the analyses of the data with the coding technique and we shall report the research evaluation, i.e. the evaluation of our findings, with specialists too, using the focus group technique.

DATA ANALYSIS

We analyzed the interview data using a qualitative analysis technique denominated coding.

Coding is an analytical technique used to extract quantitative data from qualitative datasets, such as **transcriptions of interviews**, observation field notes, journals, documents, photographs, video, websites, e-mail correspondence, and so on. A code is mostly a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data (Saldaña, 2015). Our coding process can be divided into three sequences of data clustering: audio excerpts into codes, codes into categories and categories into themes.

Clustering audio excerpts into codes

We based our code inclusion criterion on the preliminary key factors defined in the survey protocol (see Table 1). We recorded the audio of the interviews to listen and re-listen to them. Then, we transcribed the interviews verbatim. **If the subject mentioned, directly or indirectly, one of the key factors in the interview**, then we extracted the exact excerpt from their speech and, after summarizing it, we described it with one or more codes.

In order to facilitate this scheme, we performed **tasks** that we believe were productive in the coding extraction (see Figure 1).

1. We extracted excerpts from the transcribed interview and stored them in a first spreadsheet. If the interview was carried out in other language, we translated it into Portuguese (task 0);
2. We mapped each row of the spreadsheet with a excerpt id;
3. We copied this content in a second spreadsheet and summarized each line, without losing the spoken information by eliminating connection phrases, repeated or meaningless words;
4. We changed some words using synonyms and jargon of the area in order to standardize the excerpts;
5. We rephrased negative phrases into affirmative ones without losing the original meaning (e.g. “the room is not light” we rephrased to “the room is dark”);
6. We selected keywords from each row and summarized them again in a third spreadsheet;
7. Based on the keywords, we defined our codes in a fourth spreadsheet. A set of keywords can derive one or more codes;

From task 1 to 6, we simplified multi-line excerpts into a small set of keywords. This greatly helped our coding process. Using keywords, it was easier to code each row of the third spreadsheet. In some cases, we defined more than one code per row (task 7). In these cases, we split the row according to the number of codes. In each new row, we mapped a unique code with one, some or all keywords, depending on the case.

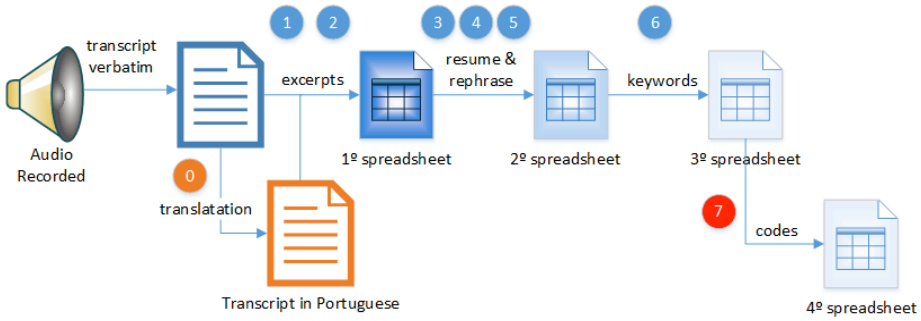


Figure 1: Coding Extraction Tasks

Clustering codes into categories

After the extraction, we organized and grouped similarly coded data into categories because they share some characteristic (patterns). We used constant comparison, scoring, filtering and clustering of codes in the analysis of each dataset collected from the interviews. That is, when we found a reference to a particular category during this analysis, we could either create a new category or refine ones that already existed. Thus, we improved the coding classification with only relevant categories.

After the categorization of all codes, we applied an exclusion criterion that we defined in our survey design: we eliminated categories that only have codes from the same subject. When this happened, we tried to reallocate the codes in other categories that have codes from a distinct subject. However, in some cases it was not possible, so we excluded the category and consequently the codes. In other words, we only maintained a category if at least two codes from different subjects belonged to this category, i.e., two subjects have to mention it. We believe that this reduces individual and biased opinions held by the subjects. Therefore, each code belongs to one or more category, and one category contains at least two codes.

Clustering categories into themes

Then, in order to discern and label the coding categories, according to the needs of the investigation, we clustered the categories into major themes. Themes reduce large amounts of codes into a smaller number of analytic units. The thematic analysis process consisted of identifying, analyzing and reporting patterns (themes) within the coding category. Using Boyatzis, (1998) approach of building a quantitative description of the frequency of themes and forming clusters of them, we identified relationships and patterns and grouped summarizing the coding categories into themes. As well as the relationship between codes and categories, each category belongs to one or more theme, and one theme contains at least two categories.

This sequence of steps, i.e. the code inclusion, categorizing the codes, category exclusion and clustering the categories into themes, is our code process that comprised the overall coding classification. A couple of samples of out coding process is available online[6]. This process was not trivial, because a code may belong to more than one category, which in turn may belong to more than one theme. In total, we built about 300 codes. We did refinement iterations and at the end of the coding process, we reduced this to 178 codes. We classified the codes into 44 categories, of which 36 are unique (i.e. the same category could be in more than one theme), which in turn we translated into 6 major themes.

We defined a coding classification for the relevant factors that might exert some influence on CM decision-making and how visualizations can address these factors. Table 2 shows part of this classification (without the codes). The whole classification is available online (in Portuguese)[7]. In some cases, a code can have the same name of a category that in turn can have the same name as a theme, e.g. "Processes" category (id 08) and "Processes" theme. This duality of name happens in all themes except for "Context". The ids of categories "Data Management", "Information Visualization" and "Decision Making" begin with the character 'P' to indicate that they are examples of processes. In Table 2, we highlighted the categories that belong to more than one theme. Bold categories are those that are repeated in two different themes, e.g. "**Technology X Employees**". Bold and Italic categories are those that are repeated in three different themes, e.g. "***Information Visualization***". Bold, italic and underlined categories are those that are repeated in four different themes, e.g. "***Decision-Making***". No category is in five or six themes.

[6] https://wiki.dcc.ufba.br/pub/SoftVis/EMVis/file_1.pdf

[7] https://wiki.dcc.ufba.br/pub/SoftVis/EMVis/file_4.pdf

Table 2: Coding Classification: Categories X Themes

Id	CATEGORIES	THEMES
01	Lack of Resources	**Context**
02	Roles of the Agencies	
03	**Technology X Employees**	
04	Geography	
05	Communication	
06	Risk	
07	Resilience	
08	Processes	
09	Lack of Processes	**Processes**
10	Unknown Processes	
11	C2 Management System (ICS)	
12	Problems on Changes	
13	Deviation from Agreed Role	
14	Bureaucracy	
15	Politics	
P1	Data Management	
P2	***Information Visualization***	
P3	***Decision-Making***	
16	Information Needs	**Data Management**
17	Information Security	
18	Data Search	
19	Data Collection	
20	Data Amount	
21	Data Heterogeneity	
22	Data Processing	
23	Transforming Data into Information	
24	Information Sharing	
25	Information Integration	
26	Information Diffusion	
P2	***Information Visualization***	
27	**Information Analysis**	
28	**Knowledge**	
P3	***Decision-Making***	
29	Check Processes	**Information Visualization**
30	Visual Paradigms	
27	**Information Analysis**	
28	**Knowledge**	
P3	***Decision-Making***	
03	**Technology X Employees**	**Human Behavior**
31	Inexperience	
32	Practitioner Competence	
P3	***Decision-Making***	
P2	***Information Visualization***	**Decision-Making**
33	Human Behavior	

Lastly, we scheduled a focus group session, based on the guideline proposed by Sobreperez, (2008). The objective is to validate our analysis, mitigating some threats to its validity, e.g. biases of the researchers.

FOCUS GROUP

We looked for domain specialists to evaluate our data analysis. We decided to carry out a focus group to mitigate our findings doing double-check with specialists, e.g. categories and themes identified by the coding.

We executed the focus groups session following similar guidelines used in the interviews. We audio recorded all the session. In the opening of the session, we asked the specialists to sign the same two terms of the survey protocol: the consent form and authorization form. After the session, we transcribed it verbatim by listening and re-listening to the recording (we carried it out in Portuguese). We also sent the session transcription to the specialists to review their positions in their own time. We decided to send the session transcription to all the subjects of the interviews. We were interested in their opinions; however, we received no email feedback.

The focus group was semi-structured and guided by six open-ended questions. As with the interviews, the discussions were not restricted by the questions, they were open-ended, dynamic and we used some improvisations on the part of the interviewer within our scope of interest. We present the questions asked below.

- Question 1 (Q1): Are any of the major themes proposed that you do not consider relevant? Please, explain your answer.
- Question 2 (Q2): Are any of the categories proposed that you do not consider relevant? Please, explain your answer.
- Question 3 (Q3): Are there any relevant themes that in your opinion are missing? Which ones? Please, explain your answer.
- Question 4 (Q4): Are there any relevant categories that in your opinion are missing? Which one? Please, explain your answer.
- Question 5 (Q5): Are there any categories in a wrong theme? Please, explain your answer.
- Question 6 (Q6): Do you have any other comments, recommendations or suggestions for improving our classification?

We held the focus group meeting on February 8, 2018 at COI, during a large event called Carnival of Salvador. We set up the meeting with two researchers and three specialists. One researcher played the role of moderator and the other one observer taking notes during the session. One specialist participated in the interviews (Specialist A), another did the pilot interview (Specialist B) and the third specialist did not participate, until that moment, in the survey (Specialist C).

We previously arranged with Specialists A and B to be silent at the beginning, so Specialist C was the first to assess the result of the coding. It was the first contact of Specialist C with our study. Therefore, to mitigate bias, i.e. to mitigate that he/she just confirmed the opinions of Specialists A and B, we decided to do this.

After a brief explanation of our goals and what we had done until that moment, we asked Specialist C if the categories and the themes are representative (Q1, Q2, Q3, Q4, and Q5). Specialist C agreed. Then Specialists A and B also validated our preliminary results positively. They gave some compliments and queried some missing categories but, after a brief discussion, everyone accepted that the 35 existing ones represented the categories they thought were missing (e.g., they missed a *'Budget Constraints'* category, however, they agreed that the "Lack of Resources" category covered this).

Regarding Q6, Specialist A synthesizes in two opinions.

"*Brazil chooses the military practices of Command and Control. Perhaps, in the last decade, due to immaturity, it was the right model, but today it is more than proven that this model is saturated"*. (Specialist A)

"*Militarism is too rigid. The problems, nowadays, are dynamics. We need flexible actions, flexible tools, each case has its particularities, which cake recipes do not solve. So I think that your model is complete and has the flexibility we need to operate in the various (crisis) cases*". (Specialist A)

In addition, Specialist B concluded.

"*The current tools do not support effective actions to reduce response time or operational errors. I think it is the reason why there are so many negative opinions in this topic. I agree with him* (with Specialist A). *I think you are researching themes that we do not give due attention*". (Specialist B)

Figure 2 summarizes our survey protocol. We started collecting data from interviews focusing on **3 key factors** (raw data, information visualization and decision-making). We selected the excerpts of the interviews where the subject mentioned one of the key factors and carried out the coding technique. We categorized the codes looking for patterns (e.g. blue code β and red code γ are in the same category). We excluded the categories that only have codes from the same subject (e.g. yellow code α). We clustered the categories in **6 themes.** We carried out a focus group with domain specialists to validate our findings. These were the steps used to develop the draft model.

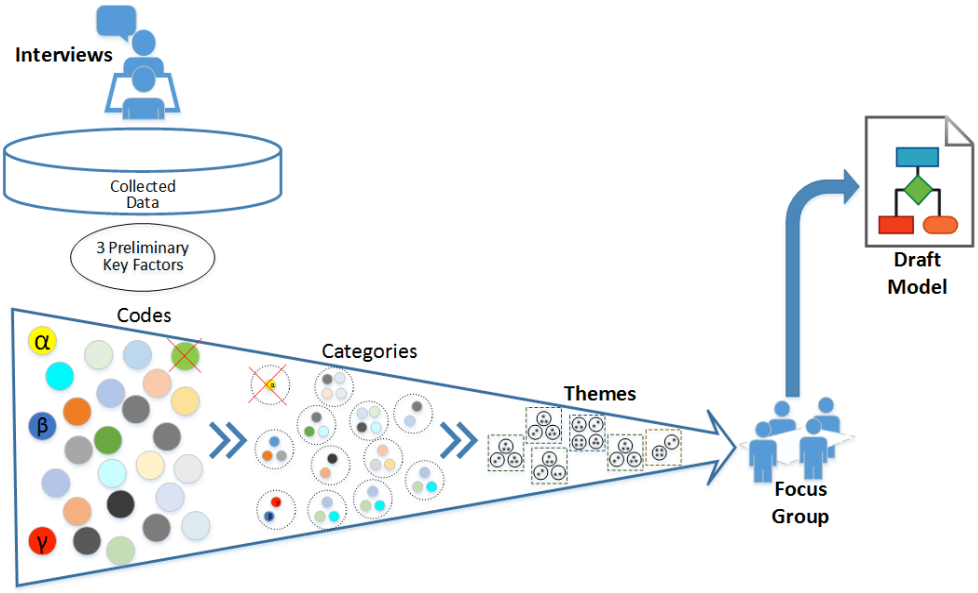


Figure 2: Summarization of the Survey Protocol

RESULTS

The use of empirical techniques based on the qualitative research approach enriched the results of this work. The partnership between domain specialists and us facilitated contact with them and helped in the execution of the activities. The tasks applied such as documents analysis, semi-structured interviews, transcriptions, translations, codings and others were not automated. It adds qualitative value to the results and decreases the possibility of errors.

Regarding the overall survey tasks: the transcriptions, translations and codings were time consuming. We spent on average five hours transcribing every 30 minutes of recorded audio. We had to repeat some audio excerpts many times pausing, going back, going forward and so on. We spent on average one hour per page translating from English to Portuguese. Our coding tasks required that all the interviewee transcriptions were in the same language. We decided to translate the interviews from English to Portuguese, and not the opposite, for two reasons: firstly, to save time because six interviews (seven with the pilot) were in Portuguese and only one in English, and secondly, we did not have authorization to publish all the data. If we had authorization to publish, this would justify the effort of doing several translations to English instead one to Portuguese for obvious reasons, since English is a universal language in academia.

As we said in **survey design**, one interview we used as a pilot study, we discarded another one, so six interviews were coding analyzed producing 116 pages of text (about 60.000 words). On average, we spent four hours on preliminary coding for each transcript (first spreadsheet in Figure 1). The other tasks, which include filling the other spreadsheets, the identification of codes, categories and themes, we spent at least 3 months in total on these tasks. The transcription of the focus group sessions was also time consuming. The session lasted about 70 minutes and its transcription produced 31 pages of text (about 15.000 words).

The main result of the data analysis is the coding classification. We build a classification with these three items (codes, categories and themes). The main idea of the coding is to synthesize the interview data (into codes) and to find patterns (categories and in turn themes) to understand the main themes for CM decision-making. With the coding result, we could identify what aspects are relevant in this area based on the knowledge of those who are familiar with the challenges of CM and face them every day in practice: the crisis managers. Thus, based on three preliminary key factors (Table 1), we built 178 codes, 44 categories and 6 major themes (Table 2).

We refined the key factors into six coding themes (**Context**, **Processes**, **Human Behavior**, **Data Management**, **Information Visualization** and **Decision-Making**). In other words, our data analysis identified the relevance of other themes, such as context, processes and human behavior, which are fundamental to decision-making. We concluded that researchers and practitioners do not pay due attention to key themes that they should be aware of and incorporate these into visualization tools. Therefore, we found out that tackling information overload is necessary but not sufficient to contribute effectively in this research area. We need to tackle another problem that we call non-dedicated information (e.g. information about crisis context, processes and human behavior).

Besides this, we believe that information visualization is necessary but insufficient to tackle both problems. During our research, we also identified gaps and trends in the area. One of these trends is the use of Visual Analytics (VA). We found works in the literature, which addressed VA in crisis contexts that, according to the authors, generated excellent results (Andrienko *et al*., 2007; Chae *et al*., 2014; Tomaszewski and MacEachren, 2012). VA enables people to detect the expected and discover the unexpected (Cook and Thomas, 2008). Keim *et al*., (2008) adjusted Shneiderman's mantra (Shneiderman, 1996) from: "*Overview first, Zoom, Filter and Details on demand*" to: "*Analyze first, Show the Important, Zoom, Filter and Analyze further, Details on demand*". In other words, this mantra is calling for the astute combination of analytic approaches together with advanced visualization techniques. VA concepts led us to research this area in our work, so our solution addressed the two problems above: information overload and non-dedicated information.

While useful, the use of VA concepts in CM may add activities to management processes that may not be easy or fast to adopt. The benefits brought by VA to analyze crisis information also come along with certain challenges. These include: (1) how to map VA concepts with the countless variables of a crisis to support the managers in quickly identifying relevant and reliable information to make decisions; (2) whether researchers and practitioners are using VA techniques and tools effectively to tackle challenge 1; and, (3) how to enhance VA applications with minimal impact on current CM activities. We believe that a computational model can be used to tackle these challenges. In turn, now, our challenge is how to develop and apply such a model.

THREATS TO THE VALIDITY

A fundamental issue of any evaluation is to discuss how valid its results are (Wohlin *et al*., 2000). The threats to the validity of our study and how we mitigated them are described below.

Poor survey design based on a poor theoretical basis could figure. To mitigate this, we did a pilot interview to evaluate our survey protocol. CM is complex and dynamic therefore; research data collection in this area is also complex. The dataset collected might be incomplete or inconsistent. We mitigated this threat by collecting data from different research sources and using different approaches; i.e. literature, documents, software, observations, questionnaires in our previous work (Dusse *et al.,* 2018) and interviews with specialists, in this present work. In addition, we compared, crosschecked and triangulated all the collected data.

Concerning the results, we coded the collected data based on our own discernment. Due to resource and time issues only one researcher carried out the coding technique analysis (ideal would be at least two researchers to carry out independently and in case of disagreement a third opinion to reach a consensus). We might have classified it incorrectly or in a biased manner. In order to mitigate this threat, we interacted repeatedly with the subjects by email, informal conversations and carried out a focus group to validate our work. Moreover, the subjects could also be biased. Hence, we only included a coding category if two or more subjects mentioned it to eliminate any individual and biased opinion of a subject. In addition, concerning the results of the research evaluation, due logistical issues, all the specialists of the focus group session came from the same institution (COI). We invited specialists from other C2 centers and we planned to make web-conference but we gave up due the complexity involved. We mitigated this threat by sending emails with the session transcription attached to other CM specialists in the world to share with them and to know their considerations.

We believe that the data collected is representative of CM. In other words, we propose that any crisis manager, in any city around the world, can use our results, in a generic way, to support decision-making. We attempted to mitigate this threat because we collected data from more than one C2 center. In addition, the qualifications and work experience of the specialists minimized the impact of this threat.

FUTURE WORKS

As we mentioned, this work is part of a broader work. In this paper, we present the results of a survey based on past works (Dusse *et al*., 2018) and mainly on interviews with specialists in Crisis Management to understand the main themes that influence the information visualization, especially VA, to support decision-making. The objective of this broader work is to develop a computational model which; independent of standards, technologies and people, and regardless of the type of the crisis; may help crisis managers to make decisions

quickly and more assertive. In this section, we briefly present a draft model designed by us with our aim towards a robust computational model based on VA for CM.

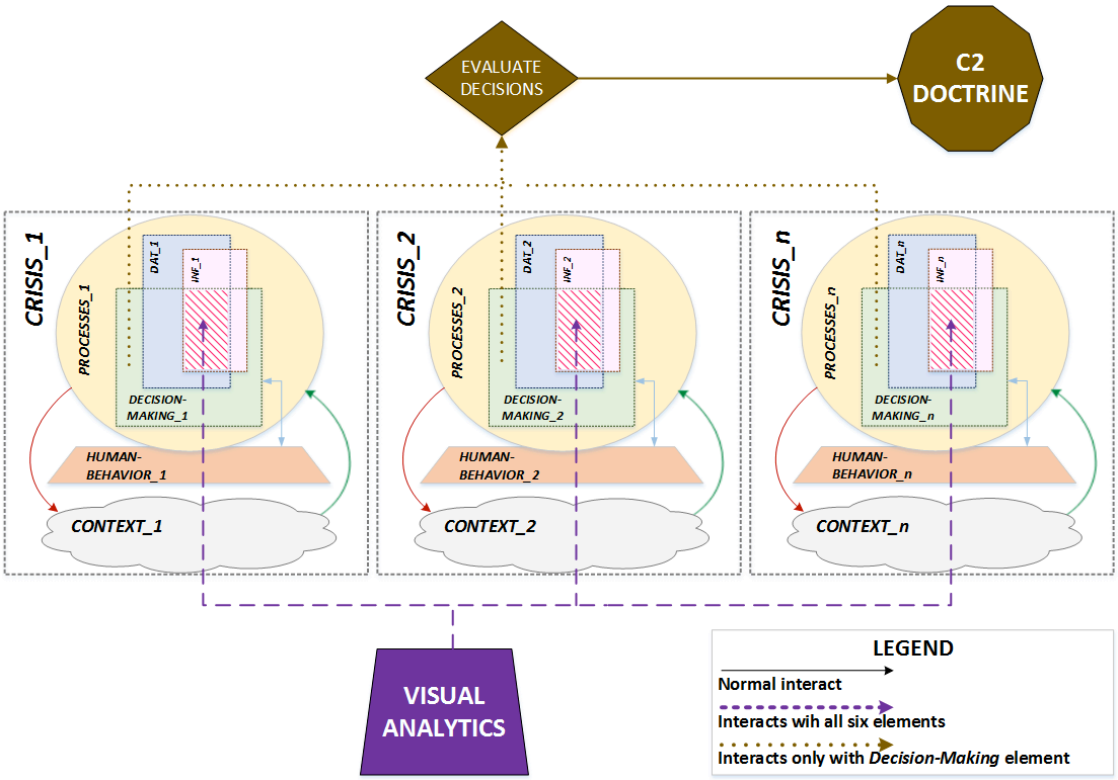


Figure 3: Draft Model

In Figure 3, we show a draft version of the model; there are two types of elements: internal to the crisis and external to the crisis. The squares are a given Crisis *n* to be managed. Within them, there are internal elements of the crisis, i.e. the six themes and their relationships. These elements are the thematic synthesis of the coding technique. From bottom to up, the first element is CONTEXT (gray cloud); as the name suggests it represents the context of the CM. The next element is *HUMAN-BEHAVIOR* (orange trapezium); in our model this element is the basis of the element *PROCESSES* (yellow ellipse), which are the process of the CM executed by humans. Within *PROCESSES*, our model represents three processes *DAT* (blue rectangle), *INF* (rose rectangle) [8] and *DECISION-MAKING* (green rectangle) elements.

The *PROCESSES* element always interacts with *CONTEXT* element (red and green arrows). In real life, the context defines which process tasks will be executed. The red and green arrows represent these interactions between the CM context with CM processes. *HUMAN-BEHAVIOR* interacts with *INF* (dark blue arrow) and *DECISION-MAKING* (light blue arrow).

The spatial positions of the three rectangles in the model are intentional. *DAT*, *INF* and *DECISION-MAKING* elements have intersections among them. The dark pink hatched area represents the intersection of these three elements. They have intersections in two by two elements and non-intersection areas. These spatial positions mean that decision-making process uses tasks of data management and information visualization processes. This modeling setting represents that information visualization is necessary for decision-making, but it is not sufficient. Other processes may support decision-making; however, this is not within the scope of our work. Moreover, information visualization tasks may be used by other processes, besides decision-making, which are not represented by our model (this is not within the scope of our work either).

Regarding the external elements (Figure 3), *VISUAL ANALYTICS* interacts with all six elements in each crisis, for obvious reasons; VA is the basis of our model. *VISUAL ANALYTICS* pass through *CONTEXT*, *HUMAN-BEHAVIOR*, *PROCESSES*, *DECISION-MAKING*, *DAT* and *INF* elements. The purple dashed line represents these interactions. The visualizations follow the VA concepts and are adapted depending on several aspects, for example, human behavior.

[8] Due to spatial position reasons, we abbreviate the name of two elements: *DAT* is Data Management and *INF* is Information Visualization.

C2 DOCTRINE is another external element. We believe that decisions made with the support of our model have the potential to improve the C2 Doctrine. We consider that our model can encourage new research in the CM area and in turn in C2 Doctrine. Specialists in CM may evaluate a set of decisions made in a set of *n* crises and may propose changes and improvements in C2 Doctrine. The brown dotted lines represent these interactions among *DECISION-MAKING* element with *C2 DOCTRINE*.

In this section, we present a first (draft) version of our aim towards model. For each of the six internal elements (themes), we will model sub-elements and relationships between other elements (internal and external). Next steps, we shall carry out other validations and improvements to the model.

CONCLUSIONS

We carried out a survey protocol to understand the overall dynamics of CM activities in depth, comprising the main themes of how managers analyze crisis information for decision-making and primarily if we can improve it by using visualization techniques causing the least impact on the structure that exists nowadays.

The **survey** was carried out in stages: the design of the survey; the execution of the survey, we interviewed eight CM specialists; the interview data analysis using the coding technique; and the evaluation of the survey, we used the focus group technique.

Our survey transformed the collected data into classes of visual needs for CM. It was possible to identify the relationships between these visual needs and other main themes of influence for CM. We found that practitioners and researchers are neglecting important themes that need to be represented in visualizations tools for decision-making (e.g. information about crisis context, processes and human behavior). In our research, we identified that the concepts of VA can tackle these themes.

As we mentioned, we will use the results of this work to guide future research directions that is the full development of the draft model presented in the previous section. Our aim is to apply the model in simulation crisis or even in real crisis case studies, improving the model.

REFERENCES

Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M. J., MacEachren, A. and Wrobel, S. (2007) Geovisual analytics for spatial decision support: Setting the research agenda. *International journal of geographical information science*, 21(8), 839-857.

Bosch, H., Thom, D., Heimerl, F., Puttmann, E., Koch, S., Kruger, R., Wörner, M. and Ertl, T. (2013) Scatterblogs2: Real-time monitoring of microblog messages through user-guided filtering. *Visualization and Computer Graphics, IEEE Transactions on*, 19(12), 2022-2031.

Boyatzis, R. E. (1998) Transforming qualitative information: Thematic analysis and code development. Sage.

Builder, C. H., Bankes, S. C. and Nordin, R. (1999) Command concepts: A theory derived from the practice of command and control. *Rand National Defense Research Inst Santa Monica CA*.

Chae, J., Thom, D., Jang, Y., Kim, S., Ertl, T. and Ebert, D. S. (2014) Public behavior response analysis in disaster events utilizing visual analytics of microblog data. *Computers & Graphics*, 38, 51-60.

Ciolkowski, M., Laitenberger, O., Vegas, S. and Biffl, S. (2003) Practical experiences in the design and conduct of surveys in empirical software engineering. *In Empirical methods and studies in software engineering* (pp. 104-128). Springer, Berlin, Heidelberg.

Claes, W., Per, R., Martin, H., Magnus, C. O., Björn, R. and Wesslén, A. (2000) Experimentation in software engineering: an introduction. *Kluwer Academic Publishers*: Norwell, MA, USA.

Cook, K. A. and Thomas, J. J. (2005) Illuminating the path: The research and development agenda for visual analytics (No. PNNL-SA-45230). *Pacific Northwest National Lab.(PNNL),* Richland, WA (United States).

Dusse, F., Júnior, P., Alves, T., Novais, R., Vieira, V., and Mendonça, M. (2016). Information visualization for emergency management: A systematic mapping study. *Expert Systems with Applications*, 45, 424-437.

Dusse, F., Novais, R. and Mendonça, M. (2018). Investigating the Use of Visual Analytics to Support Decision-Making in Crisis Management: A Multi-Method Approach. *In Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM).*

ESRI. (2009) GIS for Comprehensive Emergency Management. Online in: 〈http://esribulgaria.com/wp-content/uploads/2013/07/gis-for-emergency-management-II.pdf〉 , Available in: 31/10/2018.

Keim, D., Andrienko, G., Fekete, J. D., Görg, C., Kohlhammer, J. and Melançon, G. (2008) Visual analytics:

Definition, process, and challenges. *In Information visualization* (pp. 154-175). Springer, Berlin, Heidelberg.

Marbouti, M., Mayor, I., Yim, D., and Maurer, F. (2017). Social media analyst responding tool: A visual analytics prototype to identify relevant tweets in emergency events. *In Proceedings of the 14th International Conference on Information Systems for Crisis Response and Management (ISCRAM).*

Melnik, R. (2015) Mathematical and computational modeling: with applications in natural and social sciences, engineering, and the arts. [S.l.]: John Wiley & Sons.

Runeson, P. and Höst, M. (2009) Guidelines for conducting and reporting case study research in software engineering. *Empirical software engineering*, Springer, 14(2), 131.

Saldaña, J. (2015) The coding manual for qualitative researchers. Sage.

Shneiderman, B. (1996) The eyes have it: A task by data type taxonomy for information visualizations. In Visual Languages, 1996. *Proceedings, IEEE Symposium on* (pp. 336-343). IEEE.

Sobreperez, P. (2008) Using plenary focus groups in information systems research: more than a collection of interviews. *Electronic Journal of Business Research Methods*, 6(2), 181-188.

Thom, D., Bosch, H., Koch, S., Worner, M. and Ertl, T. (2012) Spatiotemporal anomaly detection through visual analysis of geolocated twitter messages. *In Pacific Visualization Symposium (PacificVis)*, 2012 IEEE (pp. 41-48). IEEE.

Tomaszewski, B. and MacEachren, A. M. (2012) Geovisual analytics to support crisis management: Information foraging for geo-historical context. *Information Visualization*, 11(4), 339-359.

Turoff, M., Chumer, M., de Walle, B. V. and Yao, X. (2004) The design of a dynamic emergency response management information system (DERMIS). *Journal of Information Technology Theory and Application (JITTA*), 5(4), 3.

Villela, K., Breiner, K., Nass, C., Mendonça, M. and Vieira, V. (2014) A smart and reliable crowdsourcing solution for emergency and crisis management. *Interdisciplinary Information Management Talks*, Podebrady, Czech Republic, 213-220.

Wohlin, C., Runeson, P., Höst, M., Ohlsson, M. C., Regnell, B. and Wesslén, A. (2000) Experimentation in Software Engineering: An Introduction. *Kluwer Academic Publishers,* Norwell, MA, USA.

Yates, D. and Paquette, S. (2010) Emergency knowledge management and social media technologies: A case study of the 2010 Haitian earthquake. *In Proceedings of the 73rd ASIS\&T Annual Meeting on Navigating Streams in an Information Ecosystem*-Volume 47 (p. 42). American Society for Information Science.

The Dynamics of Cyber Resilience Management

Juan Francisco Carías
University of Navarra, TECNUN, School of Engineering, San Sebastian, Spain
jfcarias@tecnun.es

Leire Labaka
University of Navarra, TECNUN, School of Engineering, San Sebastian, Spain
llabaka@tecnun.es

José María Sarriegi
University of Navarra, TECNUN, School of Engineering, San Sebastian, Spain
jmsarriegi@tecnun.es

Andrea Tapia
Pennsylvania State University, USA
axh50@psu.edu

Josune Hernantes
University of Navarra, TECNUN, School of Engineering, San Sebastian, Spain
jhernantes@tecnun.es

ABSTRACT

With the latent problem of security breaches, denial of service attacks, other types of cybercrime, and cyber incidents in general, the correct management of cyber resilience in critical infrastructures has become a high priority. However, the very nature of cyber resilience, requires managing variables whose effects are hard to predict, and that could potentially be expensive. This makes the management of cyber resilience in critical infrastructures a substantially hard task.

To address the unpredictability of the variables involved in managing cyber resilience, we have developed a system dynamics model that represents the theoretical behaviors of variables involved in the management of cyber resilience. With this model, we have simulated different scenarios that show how the dynamics of different variables act, and to show how the system would react to different inputs.

Keywords

Cyber resilience, System dynamics, Critical infrastructure protection (CIP).

INTRODUCTION

Society's welfare is dependent on the effective performance of Critical Infrastructures (CIs) to provide our energy, water supply, transportation, sanitation and telecommunications (National Research Council (U.S.), 2009). CIs are defined as systems, services and assets that are vital for the welfare of society, and whose disruption or destruction has severe impact on the health, security, safety or economic well-being of citizens and on the effective functioning of government (Commission of the European Communities, 2005). Natural disasters, terrorist attacks and cyber incidents are the main threats to which CIs are exposed to. Actually, the latter are considered by the World Economic Forum as one of the most likely global risks, with high impact in case of occurring (World Economic Forum, 2018).

The cyber-attack on a power grid occurred in 2015 in Ukraine is an example of the impact of these threats. Hackers were able to successfully compromise information systems of three energy distribution companies in Ukraine and temporarily disrupt electricity supply to the end consumers. Thirty substations were switched off, and about 230 thousand people were left without electricity for a period from 1 to 6 hours. First, the hackers compromised the network using spear-phishing emails with the BlackEnergy malware. Then, they seized control of the SCADA system, which let them switch substations off remotely, disable the IT infrastructure components and destroy files

with the KillDisk malware. Finally, they carried out a denial of service attack against the company's call center to deny consumers up-to-date information on the blackout (Lee *et al.*, 2016).

Furthermore, CIs have grown in size, complexity and interconnectivity to guarantee a high level of reliability and safety in their services, but in doing so they have also increased their vulnerability, providing more surface areas for criminal hackers to exploit. Moreover, the perspective for the next years is not satisfactory, since it is expected that the number of cyber-attacks will continue increasing causing a significant negative effect on countries and industries (ENISA, 2016). Besides, the problem could be analyzed from the all hazards approach and not limit the cyber crises to cyber-attacks. Instead, considering that cyber incidents could be "acts of God" (for example, natural disasters that compromise the systems) or "acts of man" (that could be unintentional or intentional) (Björk *et al.*, 2015), the cause of cyber incidents could be black-boxed and have a broad spectrum of threats to the functionality of the CI's systems. This context has led to increasing concern about the reliability and security level of CIs, making the creation of resilient CIs that are able to cope with crises an issue of paramount importance (Federal Register, 2015).

In the last years, there has been an evolution in the approach to address the cyber threats. The cyber security approach, which focused on protection strategies, has evolved to a more strategic and long term thinking approach called cyber resilience (World Economic Forum, 2017). Cyber resilience is defined as the "ability to withstand and recover quickly from unknown and known threats" (Linkov *et al.*, 2013). To deal with future cyber incidents it is vital to integrate physical and cyber management, strengthen resilience leadership and organizational processes, and leverage supporting technologies (World Economic Forum, 2017). In this context, cyber resilience provides a holistic approach that focuses on systems rather than individual organizations (Kaplan *et al.*, 2015).

In this paper, we present a System Dynamics model that includes the policies identified by the frameworks in the literature. This model aims to increase CI providers' awareness about the importance of investing on cyber resilience policies considering a holistic approach. This simulation model aims to show the relationships between the technical, social and regulatory factors in the cyber resilience building process that have been identified in these frameworks. The aggregated perspective of the problem given by an SD model can help security managers to design and implement more effective policies, seeking a compromise among different investment strategies such as technology, training, learning, collaboration and legal requirements.

LITERATURE REVIEW

Several frameworks can be found in the literature that define a set of characteristics, stages and policies to develop and assess cyber resilience in organizations. For example, Linkov et al. (2013) defines a matrix that helps organizations to manage adverse events. This matrix combines four domains (physical, information, cognitive and social) with four stages that define the event management cycle that a system needs to follow to be resilient: plan and prepare, absorb, recover and adapt. Thus, each cell in the matrix contains policies or actions that address the question: ''How is the system's ability to [plan/prepare for, absorb, recover from and adapt to] a cyber-disruption implemented in the [physical, information, cognitive, social] domain?''.

The National Institute of Standards and Technology (NIST) develops a Framework for Improving Critical Infrastructure Cybersecurity (NIST, 2018), that defines five stages, called functions, in the cybersecurity management lifecycle: 1) identify (develop understanding of and manage risk to systems, assets, data, and capabilities), 2) protect (develop and implement appropriate safeguards to ensure delivery of critical infrastructure services), 3) detect (identify the occurrence of a cybersecurity event), 4) respond (take actions regarding a detected cybersecurity event), and 5) recover (maintain plans for resilience and to restore any capabilities or services that were impaired due to a cybersecurity event). Each of these stages or functions are subdivided in categories and subcategories, that provide aspects to consider for cyber resilience building process. This framework has 22 categories divided into 98 subcategories. For example, the category "Asset Management" is divided into subcategories like "Physical devices and systems within the organization are inventoried", "Software platforms and applications within the organization are inventoried", etc. (NIST, 2018).

On the other hand, World Economic Forum develops its own framework combining the characteristics of frameworks developed by NIST and Linkov (World Economic Forum, 2016a). This framework uses the four domains defined by Linkov and a combination of stages defined in the two previous frameworks. The stages are: 1) Plan and prepare 2) detect, 3) absorb, 4) recover and 5) adapt. Each cell of this framework includes several policies to build the cyber resilience of the organization. For example, in the physical domain, for the plan and prepare stage, there are policies such as: "Implement controls/sensors for critical assets" or "Assessment of network structure and interconnection to system components and to the environment" (World Economic Forum, 2016a).

The described frameworks suggest the implementation of dozens of policies to build cyber resilience. Investments

are needed to develop these policies but some-times it is hard to understand and measure the impact of these policies in the cyber resilience enhancement in the short, medium and long term. Simulation models can help understand the effects of different policies over time under different conditions or scenarios. Actually, simulation models can represent the real system in a mathematically reliable way simulating the behavior of complex systems over time, enabling users to understand, train and learn about how the complex a system works (Coll, Richard & Lajium, 2011).

System Dynamics (SD) is a modeling and simulation methodology that has been used in several disciplines of research such as in engineering, scientific humanitarian sciences, economy, manufacturing and management, planning and logistics, healthcare, urban planning etc. The SD uses a top-down approach that allows to manage and analyze complex adaptive systems involving interdependencies (Forrester, 1961; Sterman, 2000). This methodology is grounded in the theory of nonlinear dynamics and feed-back control, which deals with the internal feedback loops and time delays that influence the whole system (Casalicchio *et al.*, 2007).

SD methodology allows modelling effectively socio-technical systems, consisting of human, organizational and technological parts. In particular, SD is used when the individual properties are not decisive and high-level aggregation is desired or required for management purposes. This is typically the case for management strategies and long-term planning (Iturriza *et al.*, 2018; Sarriegi *et al.*, 2008).

SD's top-down approach and its high-level aggregation allow this modeling and simulation technique to include "soft" variables whose dimensions are usually unknown and their values difficult to measure exactly (Forrester, 1980; Labaka *et al.*, 2015). This is possible because SD's approach considers high level causal relationships and the general structure of the system and not the specific values of variables (Forrester, 1980). Moreover, these variables', even though they have unknown values, cannot be left out of the model since that would be to consider they have no effect, but most of the time the effect of soft variables such "morale", "awareness" or "commitment" are known to have crucial effects on many socio-technical systems (Forrester, 1980).

These characteristics are known to be part of the cyber resilience management and building processes. On the one hand, cyber resilience development involves complex and multiple relations between variables and the presence of significant delays. The process of building cyber resilience in an organization needs to consider variables that evolve quickly, like new type of cyber-attacks or software upgrades, with others that need longer times to change, such as organizational culture or individual attitudes towards security. On the other hand, building cyber resilience involves soft variables that cannot be directly measured, such as employees' awareness, cyber resilience level, etc., but that have crucial effects on the evolution of cyber resilience management. And for these reasons, we consider that SD is especially suitable to model and simulate cyber resilience management.

Besides, through the simulation of different scenarios in an SD model, managers can determine the investment strategy that best suits their objectives and needs since they can see what the results of their investment strategies would be according to the structure of the system that has been modeled. This does not mean that the model is predictive, but that a model that follows the theoretical behaviors can give managers some awareness of what the consequences of their investment decisions are.

SYSTEM DYNAMICS MODEL

In this paper we have developed a System Dynamics (SD) model that allows CIs providers (independently of whether their private or public) to reflect on the consequences of adopting different policies to improve the cyber resilience level. The developed simulation model includes what the literature identifies as key aspects and policies to build cyber resilience and models their interrelationships. This makes the model a useful tool for exploring different scenarios to see how the implementation of some policies or lack thereof can affect the impact of cyber incidents in a critical infrastructure over time.

Due to the nature of SD, the models developed with this technique can be summarized in causal loop diagrams (CLD). CLD represent causal relationships, causal loops and interactions between causal loops through variables and arrows. In a CLD an arrow represents a causal relationship, and the "polarity" of the causal relationship is depicted as a + or – sign near the head of the arrow. In this sense, the + sign represents a directly proportional relationship (i.e. when the variable near the base of the arrow increases, the variable near the head of the arrow increases as well and vice versa), and the – sign represents inversely proportional causal relationships (i.e. when the variable near the base of the arrow increases, the variable near the head of the arrow decreases and vice versa).

As said previously, cyber resilience provides a holistic approach that focuses on systems rather than individual organizations (Björk *et al.*, 2015). This means that CI's internal and external aspects should be taken into account (Labaka *et al.*, 2013). The developed model includes both aspects/contexts: internal and external that are explained in the following sub-sections.

Internal Cyber Resilience Sub-Model

The internal cyber resilience sub-model is limited to the CI boundaries. This sub-model represents policies such as investments in technology, training, systematization and learning that are influenced by the level of awareness of decision makers. All these policies can be found in different frameworks and standards in the literature (Linkov *et al.*, 2013; NIST, 2018; World Economic Forum, 2016b).

The policies included in this sub model and their behavior are described as follows:

- Awareness represents the level of knowledge the decision makers of the CI has about the vulnerabilities and risks that surround that organization. Awareness level triggers the investments in Training, Cybersecurity equipment or both. This causal relationship is represented with causal loop notation in Figure 1.

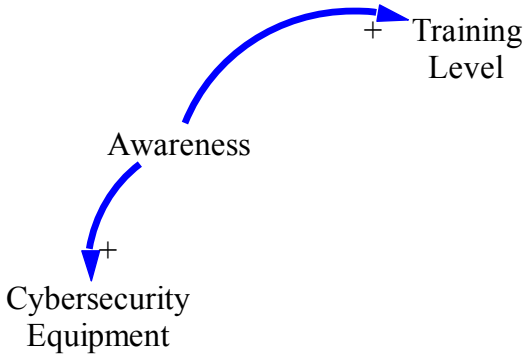


Figure 1 Relationship between Awareness, Training Level and Cybersecurity Equipment

- When the organization invests in Training the staff learns about the risks that surround the organization and the best practices currently available in order to mitigate them. Hence, the level of Training will also increase the Awareness, because as the staff gets to know more, they will be more concerned about how vulnerable the organization is because of their lack of knowledge. This added relationship can be depicted as in Figure 2.

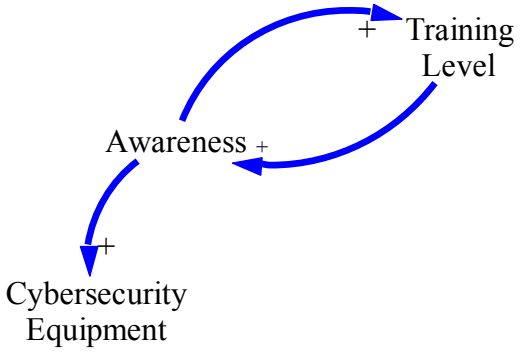


Figure 2 Training Level has a directly proportional relationship with awareness

- Systematization is the policy where internal standard processes are created to prevent incidents, mitigate them and recover from them. This policy is a direct effect of the Training policy and will only start to be applied when the staff has a certain Training level where they are able to design efficient processes. This new variable would be related to the previous ones as shown in Figure 3.

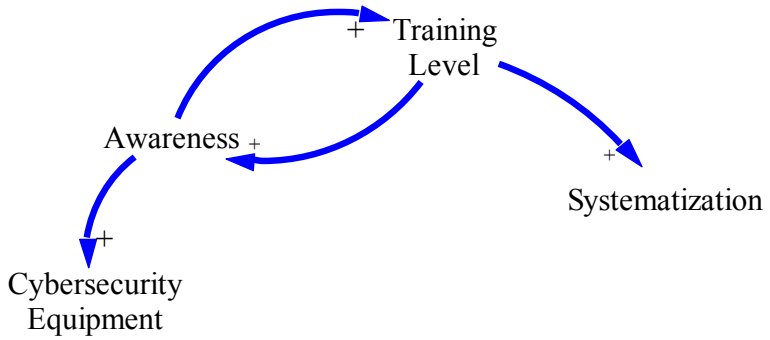


Figure 3 Trained staff can start developing systematic cyber resilience processes

- The model also takes into account the investment on Cybersecurity equipment policy. This policy represents the acquisition of software for protection against threats and detection of cybersecurity incidents.
- When the organization suffers a disruption because of an Impact event (when it has an Impact > 0) the organization's Awareness level increases. This can be represented as in Figure 4.

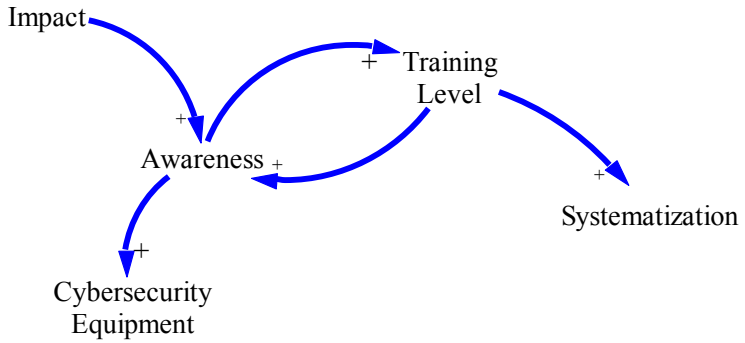


Figure 4 Impacts to the company increase awareness

In order to represent how these policies affect cyber resilience level when implemented or not implemented, they are related to the variables *Prevention capacity*, *Absorption and recovery capacity* or both. *Cybersecurity equipment* is considered to have no effect on the *Absorption and recovery*, but to have great impact on the *Prevention capacity* because most commercial software is designed to protect, and when a system is infected, protective software does not help to mitigate the crisis. On the other hand, *Training* and *Systematization* help both *Prevention* and *Absorption and recovery capacity* since knowledge of the threats, and standard processes can help the personnel recover faster from a crisis. Also, to complete the representation of the cyber resilience management, the *Internal lessons learned* variable is a representation of the adaptation stage of cyber resilience, that according to Linkov et al. is "Using knowledge from the event, alter protocol, configuration of the system, personnel training, or other aspects to become more resilient" (Linkov *et al.*, 2013). With these added relationships, the model has all the relationships shown in Figure 5.

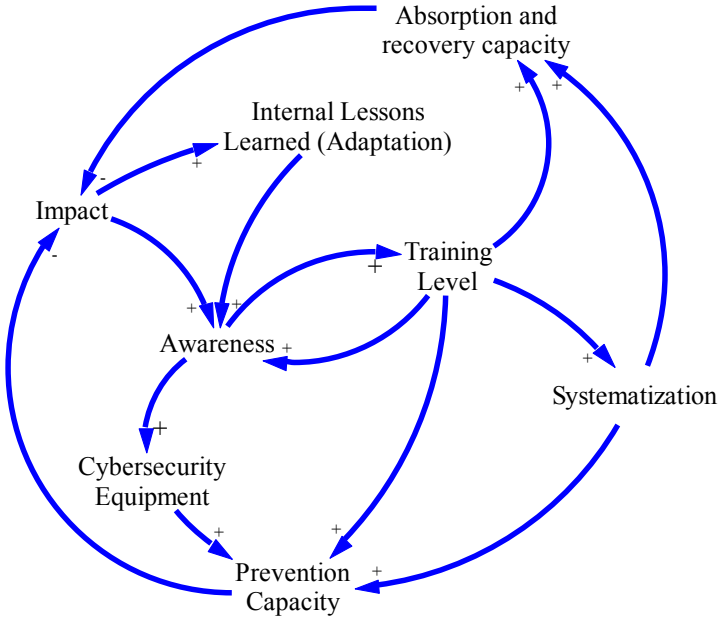


Figure 5 Relationships in the internal cyber resilience sub-model

In turn, Prevention capacity and Absorption and recovery capacity, affect the Impact inflow and outflow in the following way:

- A higher *Prevention capacity* would decrease the magnitude of the impact making the *Impact increase* be lower for any *Impact event* and as a consequence resulting in a lower value for the *Impact* stock, and vice versa.
- A higher *Absorption and recovery capacity* would decrease the recovery time making the *Impact decrease* higher, resulting in a lower value for the *Impact* stock, and vice versa.

External Cyber Resilience Sub-Model

In order to capture the effect of the external context in the cyber resilience of an organization, we have made a second sub-model that includes policies from the literature such as:

1. Collaboration: it represents how through a Collaboration policy an organization is able to learn from cybersecurity incidents that have not yet happened to them but have happened to other organizations.
2. Regulation: this sub-model represents how even if the organization does not invest in Collaboration and therefore does not learn from external cybersecurity incidents, high impact cyber events can foster the tightening of legal requirements. This tightening in legal requirements would make the organization more aware of the risks in the environment, and thus more investment on cyber resilience policies would be applied.

The behavior of this sub model is described as follows:

- External Impact is a variable that represents the incidents suffered by other organizations.
- Collaboration represents how much communication the organization has with external stakeholders and surrounding organizations. Thus, when there is no Collaboration, no matter how the External impact variable behaves, there will be no External lessons learned. On the other hand, the more Collaboration there is, the more External lessons learned increases when surrounding organizations suffer incidents. When the organization learns from what happened to other organizations, the Awareness increases as well, because the decision makers would become aware of the surrounding risks. This can be represented in CLD notation as shown in Figure 6.

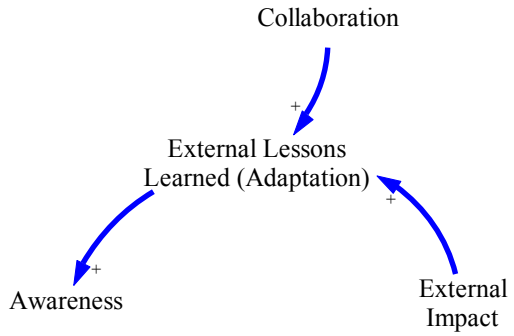


Figure 6 The lessons learned from incidents to other companies depend on the level of collaboration

- Independently of how much Collaboration there is, External Impact affects the legislation: the bigger the impact on other critical infrastructures, the more New legal requirements will appear. These New legal requirements that the organization needs to comply with, make the decision makers aware of what happens outside of the organization increasing their level of Awareness. This is the final relationship in the external cyber resilience submodel and can be represented as in Figure 7.

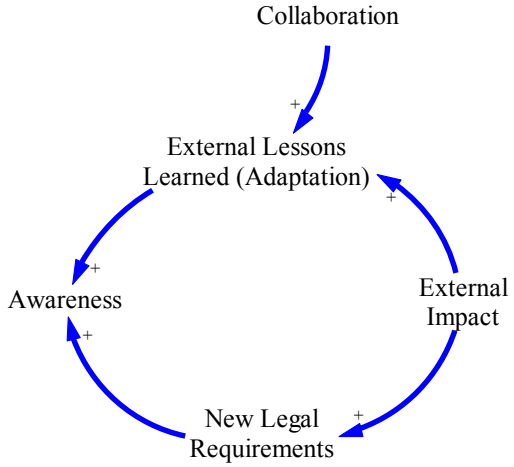


Figure 7 All the relationships in the external cyber resilience sub-model

This sub-model is connected to the internal cyber resilience sub-model because the policy of Collaboration affects the Absorption and recovery capacity, and because New legal requirements will appear when significant cybersecurity crises happen either to the organization or to external organizations. Also notice that by joining these two sub-models it is possible to model the complete cyber resilience management of a critical infrastructure.

SIMULATIONS

The effect of different policies included in the simulation model has been analyzed in the different scenarios shown in Table 1.

Table 1 Simulation Scenarios

Group	Scenario
Internal Crises	Series of internal crises Series of internal crises with no investment on training Series of internal crises with no investment on cybersecurity equipment
External crises	Series of external crises Series of external crises with no investment on collaboration
External and internal crises	Series of external and internal crises

Internal Crises Scenarios

The internal crises scenarios assume that nothing happens to external organizations and the organization being studied suffers three big crises at months 10, 50, and 90. The scenarios simulated in this model assume that there is a limited budget that can be either invested on training or on cybersecurity equipment, however, since every CI has a different budget and since when using SD the specific values of variables are not as important as the general structure of the system, this budget has been assigned through percentages. In this sense, the three internal crises scenarios that have been simulated demonstrate the behavior of the model on the following three cases:

1. A base run, where the organization invests on training and on cybersecurity equipment equally (50%-50%) according to its awareness level. This case is called Series of Internal Crises.
2. A second scenario where the organization does not invest on cybersecurity equipment, but invests 100% of its budget on training and collaboration. This case is called Series of Internal Crises with no Investment on Cybersecurity Equipment.
3. A third scenario where the organization does not invest on training, but invests 100% on cybersecurity equipment and collaboration. This case is called Series of Internal Crises with no Investment on Training.

The simulation of these scenarios shows that in the case of internal cyber resilience, investing only on training is more sustainable than investing only on cybersecurity equipment. This can be supported by comparing Impact graph on the three scenarios (see. Figure 8). On this graph, the base run shows a decreasing trend, while Series of Internal Crises with no Investment on Training run shows not only a bigger Impact with every crisis, but also with each crisis it takes longer to recover. These behaviors are due to the effect of not having Training and Systematization on the Prevention capacity and the Absorption and recovery capacity. On the other hand, not having cybersecurity equipment, makes the Impact grow at the beginning, but on the long-term the impact ends up decreasing with respect of the initial crisis.

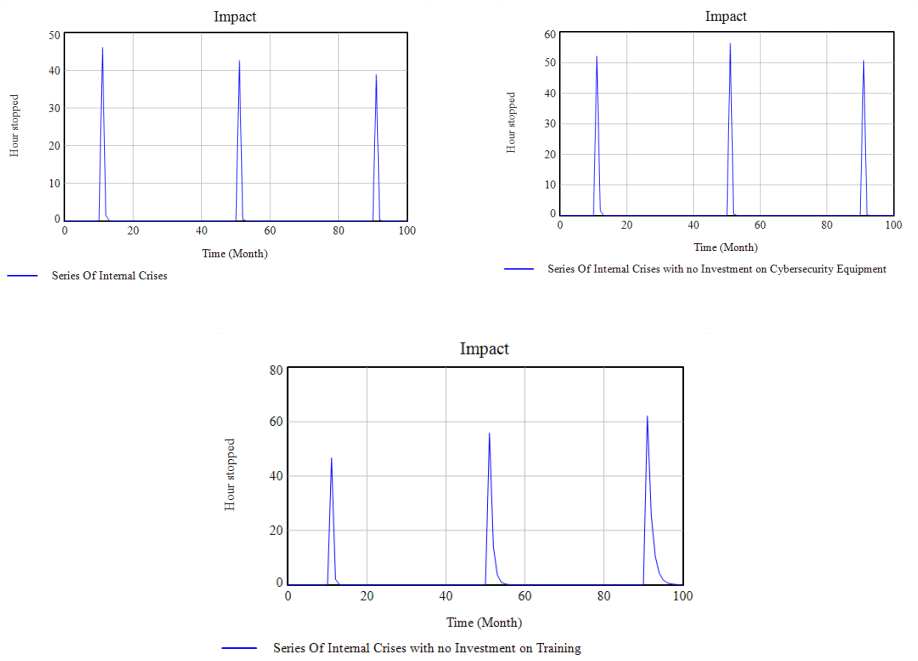


Figure 8 Impact behavior in internal crises scenarios

Another way of supporting that a training policy is of critical importance in a CI is the Awareness variable's behavior over time (see. Figure 9). This graph shows how, when not investing on training, Awareness only grows when there is a crisis and it grows because of the new legal requirements that appear and because of the lessons that are learned from the suffered impact. However, the lack awareness due to the lack of knowledge of the surrounding risks makes this kind of Awareness unsustainable, and thus the Awareness variable's trend is to decrease.

On the other hand, when there is no investment on cybersecurity equipment, due to the higher investment in training, the awareness reaches higher levels than on the base run. The reason behind this behavior is that the investment in training reinforces the management's knowledge of the risks to the CI and knowing more about the threats that the company is exposed to makes the management more aware of the problems the company may have. This behavior is also comprehensible since having more impact in the short-term would worry the

management more and thus make them more aware from the beginning.

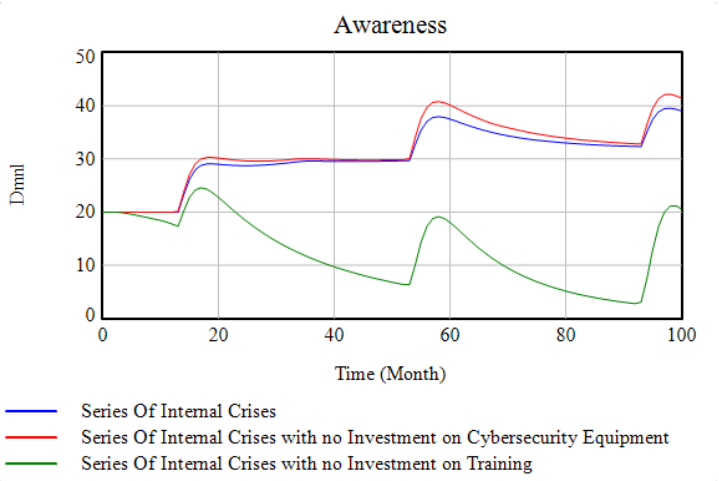


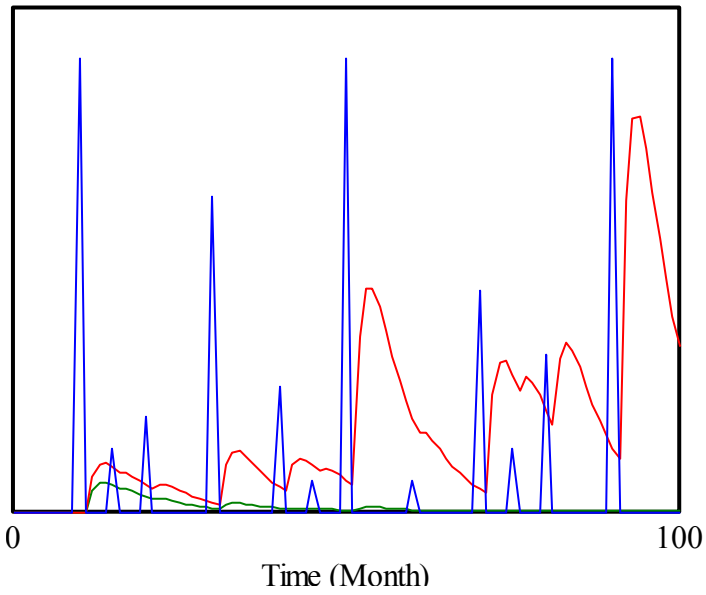
Figure 9 Awareness behavior in internal crises scenarios

External Crises Scenarios

The external crises scenario group assumes that nothing happens inside the organization but the external organizations are suffering different-sized cyber incidents over time. The two scenarios simulated demonstrate the behavior of the model on the following two cases:

1. A base run, where the organization invests in all possible policies, including Collaboration. This scenario is called Series of External Crises.
2. A second scenario where there is no investment on Collaboration, but the organization does invest in training, and cybersecurity equipment. This scenario is called Series of External Crises with no Investment on Collaboration.

The purpose of these scenarios is to show the benefits that Collaboration has on the organization's cyber resilience. These benefits can be shown by comparing the crises that external organizations have suffered and the External lessons learned that the organization acquires from those crises (see Figure 10). On both scenarios the External impacts are the same. The graph shows that, as explained when describing the model, when there is no Collaboration, no matter how the External impact varies, the organization does not learn from what happens to others. On the graph, this behavior is shown as well as an increasing learning with each crisis on the Series of External Crises case where there is investment on Collaboration.



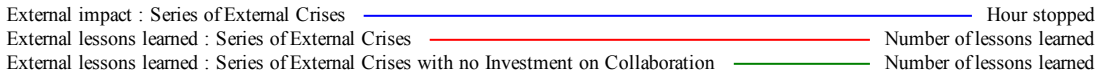


Figure 10 External impact and external lessons learned in external crises scenarios

Another result of investing on Collaboration can be observed on the behavior over time of the Awareness variable (see Figure 11). On this graph the effect of Collaboration is shown with higher values on the Awareness variable for the case where there is Collaboration. Another effect of Collaboration besides this increasing difference between the case with no Collaboration and the base case, is the increasing peaks of Awareness on crises that are a direct result of the External lessons learned that have been shown before.

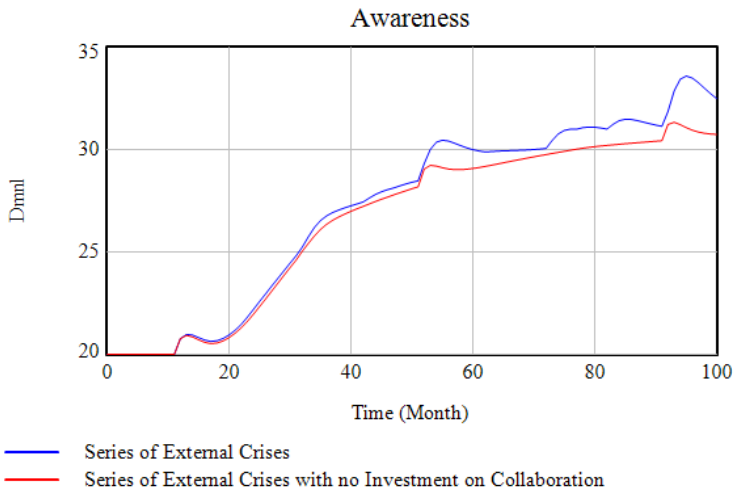


Figure 11 Awareness behavior in external crises scenarios

Internal and External Crises Scenario

Finally, the internal and external crises scenario shows how the organization would behave when there are different-sized external crises and a series of internal crises over time. To do this, the input crises for both of the previous groups have been applied. This scenario demonstrates the normal operation of the organization when it applies all of the policies that have been modelled.

As expected, the impact caused by the crises the organization suffers over time has a decreasing trend, just as it had when the *Series of Internal crises* scenario was simulated (see Figure 12). However, this time the decreasing trend is slightly steeper because of the effect of *Collaboration* on the *Awareness* of the organization. Also, in this scenario, the time to absorb and recover from the impact is also slightly smaller because of the effect of *Collaboration* on the *Absorption and recovery capacity* of the organization.

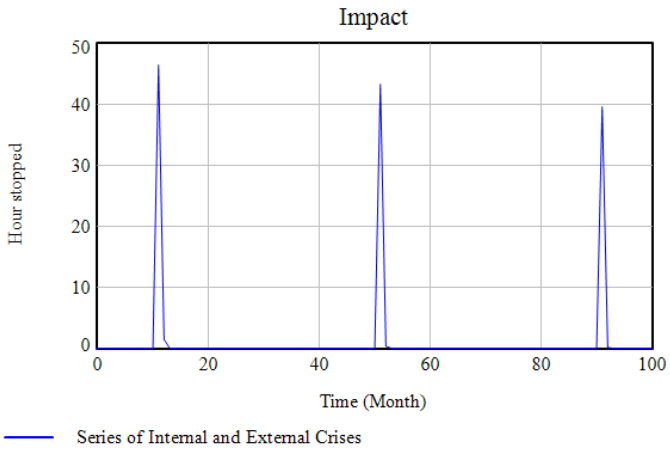


Figure 12 Impact on Internal and External crises scenario

Notice that this final scenario's behavior over time will be the sum of the base run scenarios' behaviors over time on the previous groups. This can be observed, for example, on the behavior over time graphs of the *Awareness* of

the two previous groups' base cases and the *Awareness* on the *Series of Internal and External Crises* scenario (see Figure 13). This graph shows how internal crises affect *Awareness* significantly more than external crises, and that investing on all cyber resilience policies that have been modelled when the organization is in an environment where there are internal and external crises result on more *Awareness.* This increase in Awareness, would in turn result on a better cyber resilience because of the causal relationships inside the model.

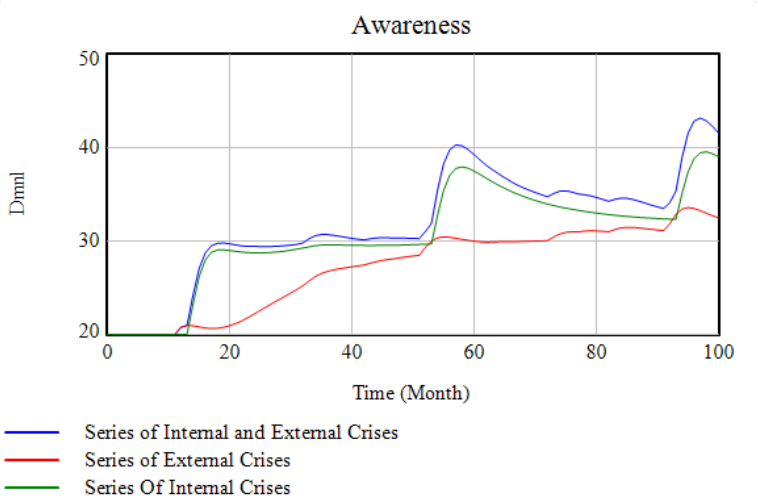


Figure 13 Awareness on the base run of the three scenario groups

CONCLUSIONS AND FUTURE RESEARCH

In this paper, we have developed an SD model that gives some insight on the management of cyber resilience on a critical infrastructure. To do this, theoretical relationships between variables related to cyber resilience have been modeled. These variables and relationships include cyber resilience domains as well as policies.

Through this model and through simulations done on it, the following conclusions have been drawn:

- When speaking about internal cyber resilience, investing only on cyber security equipment (state of the art software to protect the organization from cyber events) is a short sighted strategy that will end up having repercussion in the CI. On the other hand, investing only on training is more viable in the long term, but not ideal since it leaves the CI unprotected in the short-term.
- Collaboration with external organizations has slow results, but it adds up to help significantly to increase the Awareness as well as the Absorption and recovery capacity of the organization.
- For an optimal management of an organizations cyber resilience it is necessary to apply both, internal and external policies in the organizations resilience management plan.

The model described on this paper, however, has limitations as it is merely demonstrative and only reflects the theoretical behaviors of an organization applying these policies. Reality is much more complex and more variables are involved. This model should be validated with experts' knowledge and its limitations should be addressed in future research through the calibration of the model with real organizations' data such as a real budget and a real investment plan.

ACKNOWLEDGMENTS

The authors thank the support from the Basque Government project ELKARTEK 2017 KK-2017/00044 and project ELKARTEK 2018 KK-2018/00076.

REFERENCES

Björk, F., Henkel, M., Stirna, J., & Zdravkovic, J. (2015) Cyber Resilience – Fundamentals for a Definition *Advances in Intelligent Systems and Computing*, **353**, III–IV. doi:10.1007/978-3-319-16486-1

Casalicchio, E., Galli, E., & Tucci, S. (2007) Federated Agent-based Modeling and Simulation Approach to Study Interdependencies in IT Critical Infrastructures In: *11th IEEE International Symposium on Distributed*

Simulation and Real-Time Applications (DS-RT'07) pp. 182–189. doi:10.1109/DS-RT.2007.11

Coll, Richard, K. & Lajium, D. (2011) *Modeling and the future of science learning Models and Modeling: Cognitive Tools for Scientific Enquiry*. doi:10.1007/978-94-007-0449-7

Commission of the European Communities (2005) COM(2005) 576: Green Paper on a European Programme for Critical Infrastructure Protection, 1–26.

ENISA (2016) *The cost of incidents affecting CIIs*.

Federal Register (2015) L2: Executive Order 13636: Improving Critical Infrastructure Cybersecurity.

Forrester, J. W. (1961) *Industrial dynamics*. MIT Press, Cambridge, MA.

Forrester, J. W. (1980) Information Sources for Modeling the National Economy *Journal of the American Statistical Association*, **75**, 555–566. Retrieved from http://www.jstor.org/stable/2287644

Iturriza, M., Labaka, L., Sarriegi, J. M., & Hernantes, J. (2018) Modelling methodologies for analysing critical infrastructures *Journal of Simulation*, **0**, 1–16. doi:10.1080/17477778.2017.1418640

Kaplan, J. M., Bailey, T., Rezek, C., O'Halloran, D., & Marcus, A. (2015) *Beyond Cybersecurity: Protecting Your Digital Business*. John Wiley & Sons (US). Retrieved from https://books.google.es/books?id=hCisBwAAQBAJ

Labaka, L., Hernantes, J., Rich, E., & Sarriegi, J. M. (2013) Resilience Building Policies and their Influence in Crisis Prevention, Absorption and Recovery *Journal of Homeland Security and Emergency Management*, **10**, 289–317.

Labaka, L., Qian, Y., Lango, P., & Gonzalez, J. J. (2015) Insights from a computer simulation model of a landslide disaster *Proceedings of the Annual Hawaii International Conference on System Sciences*, **2015**–**March**, 192–199. doi:10.1109/HICSS.2015.32

Lee, R. M., Assante, M. J., & Conway, T. (2016) Analysis of the cyber attack on the Ukrainian power grid *SANS Industrial Control Systems*, 23.

Linkov, I., Eisenberg, D. A., Plourde, K., Seager, T. P., Allen, J., & Kott, A. (2013) Resilience metrics for cyber systems *Environment Systems and Decisions*, **33**, 471–476. doi:10.1007/s10669-013-9485-y

National Research Council (U.S.) (2009) *Sustainable critical infrastructure systems : a framework for meeting 21st century imperatives : report of a workshop*. National Academies Press.

NIST (2018) *Framework for Improving Critical Infrastructure Cybersecurity National Institute of Standards and Technology*. Retrieved from http://www.nist.gov/cyberframework/upload/cybersecurity-framework-021214-final.pdf

Sarriegi, J. M., Sveen, F. O., Torres, J. M., & Gonzalez, J. J. (2008) Adaptation of Modelling Paradigms to the CIs Interdependencies Problem In: *Critical Information Infrastructure Security CRITIS* pp. 295–301.

Sterman, J. D. (2000) *Business dynamics: Systems thinking and modeling for a complex world*. Irwin/McGraw-Hill, Boston.

World Economic Forum (2016a) *A framework for assessing cyber resilience*. Retrieved from http://bloustein.rutgers.edu/wp-content/uploads/2016/05/2016_WEF.pdf

World Economic Forum (2016b) A framework for assessing cyber resilience.

World Economic Forum (2017) *Advancing Cyber Resilience - Principles and Tools for Boards*. Retrieved from http://www3.weforum.org/docs/IP/2017/Adv_Cyber_Resilience_Principles-Tools.pdf

World Economic Forum (2018) *The global risks report 2018, 13th edition*. Retrieved from http://www3.weforum.org/docs/WEF_GRR18_Report.pdf%0Ahttp://www3.weforum.org/docs/WEF_GRR18_Report.pdf%0Ahttps://www.weforum.org/reports/the-global-risks-report-2018

ESCAPE: Exploring by Simulation Cities Awareness on Population Evacuation

Éric Daudé
CNRS, Normandie University
UMR 6266 IDEES
eric.daude@cnrs.fr *

Kevin Chapuis
Sorbonne University, IRD, UMMISCO
USTH, ICTLab, Hanoi

Patrick Taillandier
University of Toulouse
INRA, MIAT

Pierrick Tranouez
University of Rouen Normandie
EA LITIS

Clément Caron
CNRS, Normandie University
UMR 6266 IDEES

Alexis Drogoul
Sorbonne University, IRD, UMMISCO
USTH, ICTLab, Hanoi

Benoit Gaudou
University of Toulouse Capitole, IRIT
Sorbonne University, IRD, UMMISCO
USTH, ICTLab, Hanoi

Sebastien Rey-Coyrehourq
CNRS, Normandie University
UMR 6266 IDEES

Arnaud Saval
University of Rouen Normandie
EA LITIS

Jean-Daniel Zucker
Sorbonne University, IRD, UMMISCO

ABSTRACT

Partial or total horizontal evacuation of populations in urban areas is an important protection measure against a natural or technological risk. However, casualties during massive displacement in a context of stress and in a potentially degraded environment may be high due to non-compliance with instructions, accidents, traffic jams, incivilities, lack of preparation of civil security or increased exposure to hazards. Working in evacuation plans is therefore fundamental in avoiding casualties caused by improvisation and in promoting self-evacuation whenever possible. Since it is impossible to re-create the conditions of a crisis on the ground to assess such evacuation plans, there is a need for realistic models in order to evaluate them using simulations. In this paper, we present the ESCAPE software framework that helps in the development of such plans and testing them. In particular, ESCAPE, which uses the GAMA open-source platform as a core component, provides an agent-based simulation tool that supports simulation of the evacuation of a city's population at fine temporal and geographical scales. The framework was developed such that it works for a wide range of scenarios, both in terms of hazards, geographical configurations, individual behaviors and crisis management. In order to show its adaptability, two applications are presented, one concerning the evacuation of the city of Rouen (France) in the context of a technological hazard and the other pertaining to the evacuation of the district of Hanoi (Vietnam) in the event of floods.

*corresponding author

Keywords

Mass Evacuation, Individual Behavior, Crisis Management, Agent-Based Modelling, Geographical Information System

INTRODUCTION

High concentration of critical infrastructure and decision-making power in increasingly urbanized spaces makes risk and disaster management highly complex (Perrow 2007). Population evacuation may be the only effective response to the risk, which generally increases with urbanization rates on the coastlines and in deltas, the presence of factories in areas of high population density, and climate change. Strategy planning therefore becomes a crucial concern, however, its evaluation outside a crisis context is difficult. Indeed, while it is very important to prepare populations and organizations to face such events with the help of exercises or educational programs, there are many aspects that cannot be foreseen, *e.g.* side effects that prevent people from leaving the area or communicating, or behaviors that cannot easily be anticipated, such as people panicking or not following recommendations. Furthermore, during extreme events, new risks emerge from the actions and interactions between individuals in a potentially hostile (flood, hurricane) and degraded (closed road, broken bridge) environment. All of this can further increase the vulnerability of people who need to be evacuated and the occurrence of incidents: accidents, traffic jams, incivilities, panic situations, lack of preparation for civil security events, increased exposure to hazards... For example, the 55 deaths recorded during the Hurricane Rita in Texas were associated with the evacuation process rather than the storm itself (Knabb et al. 2006). Absence of an organization such as an emergency and crisis management authority and lack of a risk culture among the concerned population are thus important factors of territorial vulnerability.

Mitigation of risks associated with an evacuation then requires an improvement in the risk culture of populations as well as better operational knowledge among evacuation managers. This must integrate confrontation with potentially unforeseen situations, such as traffic congestion, a broken road section on an evacuation route or the dispatch of contradictory orders by different crisis management players. Drills are usually designed to deal with these requirements (Chalaris et al. 2018): these are however difficult to implement, expensive and time-consuming, and they do not allow one to re-create the actual response of individuals to stressful and potentially harmful situations. Computer simulation is taking over, as it relies on increasingly realistic models. The aim is to explore the collective impact of thousands of individual decisions taken in contexts of stress, imperfect information and potentially degraded environment.

Agent-based models (ABM) (Zucker et al. 2008) are particularly well-suited for studying how individuals with heterogeneous behaviors in mutual and environmental interaction can influence the overall dynamics of an evacuation partly controlled by an organization. This modeling makes it possible to approach realism in behaviors (capacity of displacement, perception of the environment, objectives) while differentiating the agents (motorists, pedestrians, public transport, civil security). It also makes it possible to integrate geographic data (land use maps, transport networks) and social data (number of inhabitants, road traffic) into the models with a very high level of detail (age, gender, risk culture). This approach enables the researchers to observe the dynamics of the system at various scales, that of the agent or that of the entire system, thus opening up many possibilities in terms of agent granularity. The citizen has local information of the situation, that is to say, the information, which he gets through his senses, enabling him to move or the information, which he gets through his social network, helping him to make a decision. The organization gets broader information on the situation from its sensors in the field (cameras, civil security agents, probes) and can activate its plans. This type of model is also very flexible - it is easy to change a behavior, a spatial attribute or a proportion - and can therefore be used as an artificial laboratory to test many hypotheses (Daudé 2008).

This paper presents ESCAPE, an agent-based framework dedicated to the study of mass evacuation strategies of territories under the threat of imminent events due to natural or technical hazards. A preliminary description in figure 1 shows the main components of ESCAPE: hazards, territorial issues, planning and realization of crisis management that foresees a population evacuation.

With the help of this schematic description of the field of knowledge, this paper aims to propose a conceptual framework and a software architecture (ESCAPE) for mass evacuation using an agent-based model and GIS. It is organized around four main modules:

- the **Environment** module is related to the spatial and demographic description of the simulation domain. It makes it possible to describe the territory by identifying the main issues exposed in a perimeter of potential danger. These critical issues include the population, transport networks, energy, public institutions;

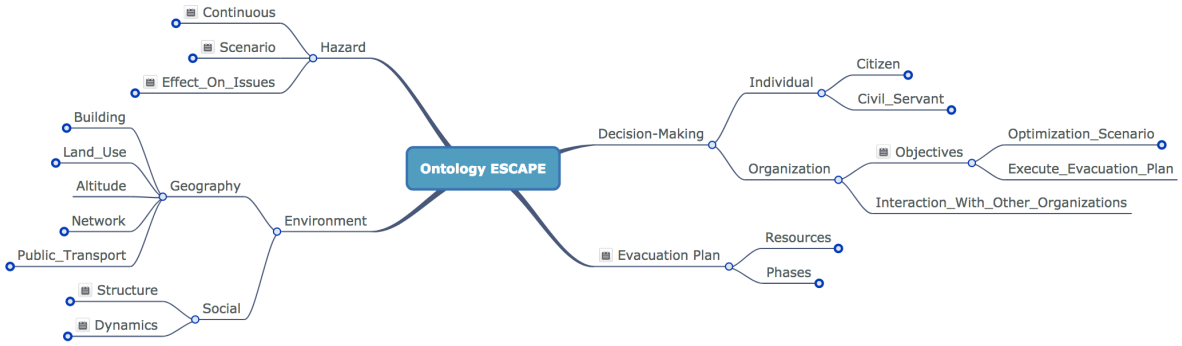


Figure 1. General diagram of ESCAPE

- the **Hazard** module makes it possible to describe all the characteristics of a hazard and provides some modeling tools. It enables the integration of various levels of spatialized hazard intensity by geographical information layers, as well as the construction of dynamic propagation models of a hazard;
- the **Crisis Management** module aims to define available resources which can be used by the organization to operationalize a plan and launch it in phases depending on various scenarios of hazard dynamics.
- the **Decision-Making** module focuses both on features related to individual mobility, including travel choices, motivations and goals that can be influenced by hazards, as well as on the disaster management authority. We will see that cognitive processes govern agent mobility behaviors as well as the behaviours of organization, whether it is strategic (plan to follow) or tactical (adjust or cope with the unexpected) behavior;

The first section gives an overview of mass evacuation models developed within an agent-based model's meta-framework. The second section presents the four core blocks of the ESCAPE framework: spatial and demographic data management, hazard dynamics, decision-making behavior and evacuation planning. The third section presents two ongoing applications of ESCAPE: traffic dynamics in Rouen (France) under the threat of industrial accidents and pedestrian evacuation of a district in Hanoi (Vietnam) during a flood event. The results of these applications are discussed in the fourth section that also leaves the door open to further developments.

MODELLING MASS EVACUATIONS

To meet the requirements of planning and crisis management adapted to specific contexts, ESCAPE proposes to develop realistic models, as well as describe the environment, the population and the mobilities in various contexts, from normal to crisis situations. On this point, ESCAPE stands out from most of the existing tools that are oriented towards simulating traffic in normal and mono-modal conditions. We propose tools for multi-modal displacement modeling taking into consideration the agents' cognitive capacity that allows them to change behavior depending on the context and the means to achieve their objectives.

While well-known traffic frameworks, like MATSim, TRANSIMS, SUMO or SimMobility, make it possible to model day-to-day urban traffic, most of them have limitations when used to study disruption induced by extreme events (Czura et al. 2015a). However, several extensions have been proposed in order to adapt these frameworks to the study of mass evacuation: MATSim provides a dedicated extension to study evacuation (Lämmel et al. 2009). Several proposals use the template (Kim et al. 2017; Zhu et al. 2018) for Tsunami and Hurricane evacuation with a simplification in the modelling: pre-computed Origin-Destination (OD) escape trips based on MATSim's iterative optimization process. Locally, simplification is also seen in terms of a first-in first-out model for micro traffic simulation. The SUMO extension called VEBEN++ has been used to study disruption in traffic due to uncommon events (Flötteröd and Erdmann 2018). Unfortunately, as for MATSim, it requires all possible pathways including the evacuation ones to be pre-computed. This is a major issue due to the fact that hazards and social dynamics during the event can have an impact on this environment. For example, one cannot predict that a major road would be blocked during evacuation not because of the flood but because of a major accident. It is this almost impossible to pre-compute all possible pathways given such uncertainties. Moreover, the pedestrians' walking model is based on dynamics that are very close to those of vehicles and does not reflect the actual people movement in crisis situations (Beck et al. 2014): pedestrians move over a network made up of virtual lanes called stripes but can neither use free walking areas nor can they cross roads outside of crossing sections. Several other platforms have been used including AIMSUN (Afzal et al. 2017), VISSIM (Harten et al. 2018), or Paramics (Chen and Zhan 2008) to study

evacuation from a regular traffic simulation platform. These are all based on the study of traffic demand and supply in specific circumstances of evacuation, for example, focusing on traffic mitigation optimization (Harten et al. 2018) or evacuation strategy comparison (Chen and Zhan 2008).

So, even if agent-based models studying traffic evacuation come in great numbers, there is no dedicated framework to the best of our knowledge (Hawe et al. 2012). Furthermore, except for traffic related platforms, agent-based evacuation models often do not incorporate complex transportation systems (Wang et al. 2016) nor a smart organization responsible for evacuation management. For the modelling platform, we choose GAMA, an agent-based development framework (Grignard et al. 2013; Taillandier et al. 2018). It has been used recently to study evacuation and traffic during a catastrophic event (Valette et al. 2018; Czura et al. 2015a; Adam and Gaudou 2017). The platform has several well-suited features such as GIS native integration and simple traffic-related primitives for car (Taillandier 2014) as well as pedestrian mobility over both network and continuous topology (Chapuis, Taillandier, Gaudou, et al. 2018). This is the framework we choose for the development of ESCAPE.

ESCAPE: AN AGENT-BASED AND GIS FRAMEWORK TO MODEL MASS EVACUATION

The ESCAPE framework is organized around a combination of geographic information systems, agent-based modeling, and simulation exploration methods. Using this framework, we produce a virtual laboratory which allows us to import layers of geographic information describing a territory and its issues with respect to a potential hazard whose intensity is scripted or described using a simulation model. This framework allows us to describe crisis plans based on hazard thresholds and actions to be initiated, as conditioned by available resources. Organizations are then in charge of executing the plan according to a scenario defined either by the user or by the dynamics of the hazard's model. The main dynamics of the ESCAPE model concern individual agents, who will react, or not, to the perceived, assessed or real dynamics of the hazard. The focus here is on a plan that provides for evacuation, with information that is then disseminated to agents and an environment, especially for evacuation routes, which can be modified accordingly. The framework provides tools for observing and diagnosing evacuation efficacy.

From the modeling of catastrophic events to traffic-related behavior and evacuation/containment plan integration, the framework aims at facilitating the modeling process by integrating modules into a single agent-based modeling solution: all tools have been integrated as one or multiple plugins to the GAMA platform. It includes primitives to manage input data for transportation support, demographics and hazards; various algorithms related to traffic modeling for vehicles, pedestrians, public transport and all the infrastructure; the ability to design evacuation/containment plans and the indicators to assess their quality or make comparisons between them; the Human Machine Interface to create, organize, manage the needed input and the generated output of these evacuation/containment plans. The following sections detail each of the components required in ESCAPE.

Environment Module

The environment module makes it possible to describe the geographical and social space as well as the daily mobility in the study area. The central concepts are depicted in Figure 2 using Unified Modeling Language (UML) class diagram: the geographical space is made of *Area* and *Transportation network*, while the demographic part comprises a description of *Human* people, including their daily mobility activity, and the *Household* they belong to.

In ESCAPE, an *Area* is a spatial object with associated geometry (point, line, polygon, etc.) where people can either walk through, like a park, or cannot cross, like water bodies (*e.g.* river, lake). Some areas have special features: for example, a building can have a certain number of floors and a capacity of reception if it is a public building. Transportation networks provide the medium for agent mobility. These are made up of edges and node intersections, and can stand for private vehicles, pedestrians or public transport. The last aspect concerns human agents and the households they belong to: Every human agent is endorsed with demographic attributes, like age and gender, and an agenda that describes the purpose and mean of its mobility expectations. Households gather humans in family groups, with an associated role (*i.e.* parent, child, other) and at least one home place location (*i.e.* a building). In the following sub-sections, we describe the concepts related to the environment module.

Human and Household: synthetic population generation

Individual characteristics (age, gender, affiliation to one or more social and / or professional networks) have a great impact on mobility behavior (Luo et al. 2016) as well as on the response to a crisis situation and evacuation (Bañgate et al. 2017). Hence, it is important to have a synthetic population of agents that represents the targeted population accurately. For this purpose, census data constitutes a crucial resource for calibrating the model of the population studied. This data is not systematically available and many countries have only sparse statistics to offer. Regarding ESCAPE, the synthetic population is generated using the Gen* (Chapuis, Taillandier, Misslin, et al. 2018) plugin

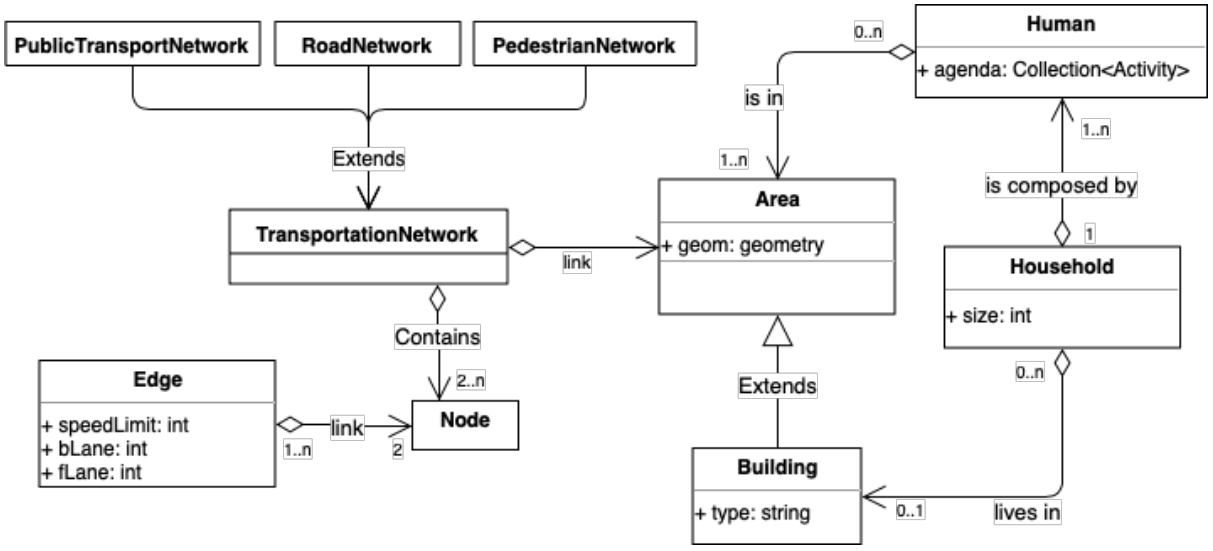


Figure 2. UML class diagram of the environment module in ESCAPE

for GAMA [1], that makes it possible to create individuals grouped into households and to give them attribute values, for example a gender and age for an individual or the number of vehicles and dwelling types for a household. The library provides several well-established algorithms, state of the art synthetic reconstruction and combinatorial optimization techniques (Müller and Axhausen 2010) respectively to create or to replicate known individuals and households according to the available data: either micro-data (sample), aggregated data or both. In addition, every household has a default home place to be linked to, *i.e.* a building as defined in the environment module (see sub–section Transportation network and Area), according to customized spatial distribution. Based on the same principle, any individual of the synthetic population can be linked to several spatial objects, like a workplace, a school or a preferred shopping center. For each agent, we can then define a list of all the places that he or she will visit at different moments of the day and on different days of the week. An individual activity space can be defined based on specific studies such as household displacement survey (Czura et al. 2015a), social networks (Cebeillac et al. 2017) or based on a rough hypothesis such as the relation between age and activity type. Another important issue in the definition of the population and its location lies in taking into account people who do not reside in the area but may be present at the time of an event: this is the case for those present because of tourism, leisure or professional activities. Another aspect which may be important is the determination of the non-autonomous population (isolated, elderly, disabled, hospitalized, imprisoned) which will imply repeated bus trips to evacuate them.

Transportation network and Area: GIS data integration in ESCAPE

Spatial data is also mainly used to set up the simulation environment. Our framework provides an input data structure, with a mandatory and optional setup to design the simulation environment (Grignard et al. 2013). It allows us to build basic blocks within the ESCAPE framework: the road network, public transport, walking areas and all the obstacles like buildings and water bodies.

Road network. The road network is the main medium for the traffic model. It can be set up using raw OSM data or custom vector shapefile. Required features include the number of lanes, direction and speed limit for the roads. The road network is composed of roads as edges, defined as polylines, and the nodes depend on OSM's nodes or the shapefile's nodes. In our proposal, the network is made up of active road and node agents: roads register users and give them information about speed limit, the number of lanes and the other connected roads. They can also handle traffic dynamics when computer efficiency is a concern, turning into a single agent aggregating all concerned vehicles, by using the same approach as the one presented in (Banos et al. 2017). The nodes can be intersections when 3 or more roads are connected to it, bus stop, evacuation or simple node. Intersections have two basic actions: give directions according to vehicle destination and manage traffic signal. The impact of road and intersection agents on traffic dynamics is detailed in section Human agent and mobility.

Public transport. The public transport plugin requires two types of information in order to operate: spatial data and time data. As for the road network, spatial data can be set up using OSM or a shapefile, and consists of a path and a

[1]Both the source codes are available on github : https://github.com/ANRGenstar

list of stops, for each transport line. The path is used to control the bus routes, by lowering the weight of roads during Dijkstra computation. Stops are merged into the road network by splitting the closest road, if required, and creating a new node. The time data constitutes the schedule sheets (one for each line), similar to those displayed at bus stops, but in the CSV format. The time data is used to simulate bus departures, and the time they are supposed to be (or wait) at each stop. Here is a sample CSV schedule file:

```
Stop 1 , 05:53 , 06:10 , 06:34 , 06:44 , 07:02 , 07:07
Stop 2 , 05:58 , |     , 06:39 , |     , 07:07 , |
Stop 3 , 06:03 , 06:15 , 06:44 , 06:49 , 07:12 , 07:12
```

In this example, the first bus will be created (or activated if a pool of buses is defined) at the cycle corresponding to 5:53, and should arrive at 5:58 at Stop 2 and at destination Stop 3 at 6:03. The following one starts at 6:10 and goes directly to Stop 3 for 6:15 (| is a skipped stop). We planned to use the GTFS[2] standard at first, but a flat file is more adapted to our case. We decided to create a script to generate a compatible set of files from a GTFS database. It is however dependent on the data quality, since GTFS is generally not respected perfectly (Kujala et al. 2018).

Walkable areas. Pedestrian agents are able to walk in specific areas, called walkable areas, following an overprinted virtual pedestrian network: the first one is constructed combining the area with the attribute *walkable* turnint it into a true and free space, that is the overall studied area minus all obstacles (buildings by default, but can be extended to any spatial object); the second one is inferred from former areas using Delaunay's triangulation. The algorithm creates nodes on the triangle's segments that are not in contact with obstacles. Then, one or two links are created between nodes of each triangle in order to create a minimum number of cross-sections, while triangles with only one segment free from obstacle are defined as dead-ends (Chapuis, Taillandier, Gaudou, et al. 2018). A combination of the virtual network and walking areas is used for pedestrian traffic movement (see section Human agent and mobility).

Non-walkable areas. Buildings are static spatial entities (polygons) that populate the geographical space of the simulation. Building attributes will be used by individuals to drive strategic goals in the traffic model: localization of the activity places such as workplace, school or home. It is possible to assign a certain number of floors and a refuge function to the building. In the first case and according to the nature of the hazard, a number of floors above a submersion wave, for example, may cause a building to become a vertical evacuation site. In the second case, the shelter is a building open to public and can be used as a confinement site inside the danger zone in the event of an industrial alert. It may also be outside the danger zone, the refuge then being a building previously identified and equipped to shelter a determined number of evacuated people. Non-walking areas also include non-building spatial entities like water bodies.

To summarize, this first *environment module* provides tools to give a detailed description of (i) the geographical area (elevation, road-network, building, walkable area, water body), and (ii) the population present on the territory at the time of the decision to evacuate, or the triggering of the hazard. Each agent can be defined on the basis of demographic characteristics, be attached to a family unit, can be autonomous or not in terms of mobility, be associated with a place of residence that can be outside the simulation zone and have a list of places he or she visits, regularly or otherwise. As this data is used to instantiate the initial population, one can define other attributes which may be of interest to simulate individual behaviors. These attributes may represent knowledge about risk and security instructions as well as emotional factors. All these attributes could be used by cognitive tools that take the thought-processes, decisions and reactions (see section Agent cognition) into account. The next paragraph presents the second module dedicated to hazard description.

Hazard Module

ESCAPE Framework features hazard modeling library tools that enable simulation of disastrous events with increasing complexity: from static spatial objects to dynamic agents. The simplest way to model such type of events is to define a static object to be triggered at a certain time and/or space during the simulation. This object can represent the possible impact zone related to a Seveso accident (see section Industrial hazard case study). Each object, whether static or dynamic, has attributes that serve to qualify its potential impact on the issues, *i.e.* the environment, the human agents and / or the organization. These attributes can be a water level and speed associated with a spatial footprint, a lethal effect for agents present in the zone or the blocking of roads in the perimeter subject to the extension zone of the hazard. It is possible to produce scenarios for the evolution of a hazard, in the form, for example, of nested zones whose transition from one to another in time and in space is based on past events (for

[2]General Transit Feed Specification

example, a flood) or a hypothetical scenario which mimics the growth of the spatial area representing the event. Modelers can provide as many extension zones describing the spatio-temporal dynamics of the hazard as necessary. These objects and the transition scenario from one to the other can then be used as indicators for triggering a warning system and a crisis management plan (see section Crisis Management).

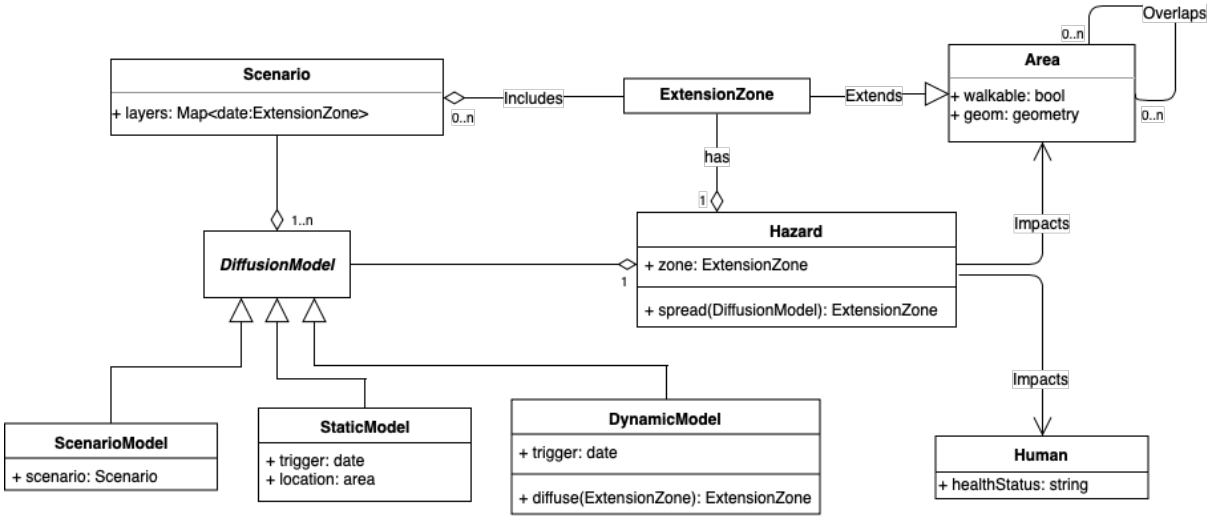


Figure 3. The UML class diagram of ESCAPE hazard module

Another way to represent the evolution of a hazard or danger consists in generating a catastrophic event using dynamic diffusion rules. We provide two methodologies to generate this kind of events: extension over cells of a cellular–automata or moving geometries over a continuous space. The first one consists in splitting the spatial area of study into cells of equal size, e.g. 20 x 20 meter square that cover the overall studied area, and mimic the evolution of the event by the diffusion of properties and values from cell to cell. For example, one cell can be on fire and diffuses fire to adjacent cells following a diffusion equation that can include any process, like direction of wind or the amount of combustible. The initial distribution of the variable to be diffused can be easily set up using GIS data. The second option is close to the scenario-based representation of a hazardous event: starting from an extension zone, e.g. shapefile of a river or the footprint of a building on fire, the spatial object representing the catastrophe can be extended using agent-based spreading rules. In this extension, each vertex of the hazard spatial object is an agent that will apply the spreading rules: for example, a flood spatial object could have vertices speed up by decreasing or slowing down with increasing elevation, stopped by obstacles such as buildings, or splitting up when reaching a threshold distance between them. Generative solutions can be useful in two cases: when data is missing or when one wants to explore several catastrophic developments from a base scenario.

To summarize, this second *Hazard module* makes it possible to develop an ESCAPE scenario in a specific zone with really crude data, for example, only one shapefile giving a specific zone to evacuate in order to define the best evacuation roads and evaluate the delay of evacuation. In this case, one can assume no interactions with the hazard, which is in many cases the aim of preventive evacuations. One can also import several layers representing the spatial and temporal dynamics of the hazard. In this case, ESCAPE provides tools to configure the delay between each layer in order to simulate the speed of the event. Finally one can choose to model the hazard dynamics with CA or moving geometry. This last possibility is interesting in case there is no information about the possible spatial extent of a hazard or if one has only its maximum extension value.

The realism of the simulations thus requires, for these two previous modules, a precise description of the territories concerned by the hazards and their stakes. The use of a geographic information system makes it possible to structure this data. This realism also involves a detailed description of the population to be evacuated. With the use of agent-based modeling, each agent is differentiated according to several criteria: gender, age, family composition ... Each agent will also have a perception and representation of his environment, and will be able to act accordingly, which we will see later in this paper. Before that, the next section presents the third most important module in ESCAPE which allows the description of means implemented by public and private actors to make the territories less vulnerable to these hazards. In particular, it insists on crisis management and its strategic and operational aspects.

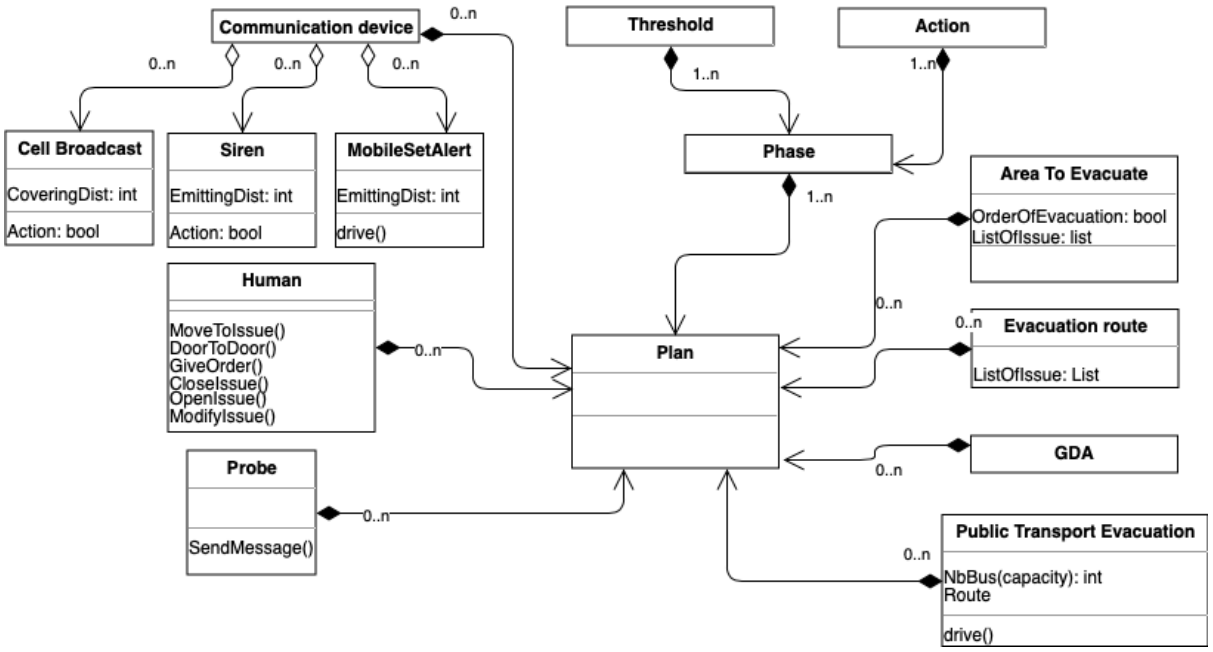


Figure 4. The UML class diagram of ESCAPE evacuation plan module

Crisis Management Module

Whenever an evacuation is required, whether it must be accomplished urgently (Tsunami) or spread over time (cyclone), the objectives are the same: How does one alert the people? By what means can we get as many people out of this geographical area as possible in the shortest possible time? How to organize bus routes so that they cover the widest possible area and collect the largest number of people? How to offset population departures in order to limit network congestion? How to deal with people who are not residents and who are not familiar with the evacuation procedures? The possibility of describing an evacuation plan or confinement strategy with ESCAPE is then a crucial issue. It must be a means to evaluate existing evacuation plans depending on factors such as the number of casualties or the time of complete evacuation.

On the basis of spatiotemporal hazard scenarios identified hereinabove, emergency planning zones can be defined and measures for the protection of the population worked out by the different authorities. Evacuation plan description can be schematically split into two categories, one related to available *resources*, both material and immaterial, and one related to the *phases*, *i.e.* the different stages of use of these resources according to the evolution of the hazard and of the plan itself (see figure 4).

Available resources

Planning involves deploying along a scale, (hazard intensity-based, time-based or alert-based) divided into a finite number of phases, a series of actions that mobilize resources to accomplish a program. Our framework provides optional setup to design available resources, *i.e.* but one can simulate self-evacuation of people to explore the overall effect of a lack of strategy. A certain number of human resources, probes, buses or shelters are all resources which can be used in a plan to conduct an evacuation.

Checkpoints and probes in the territories. Observation of an evolving hazard in a territory is an essential factor to start an action plan as soon as possible and to make it evolve during an event. Probes are agents placed in the environment to record specific attributes, such as the water level or wind speed. We can locally use these probes to follow the evolution of a hazard described from a dynamic model. We can also use these probes to follow traffic congestion, as does video surveillance, for example. This information can be provided to the organization, automatically or on demand, to trigger or to decide the type of actions to be taken.

Communication device. Evacuation implies alerting and keeping the people informed during an event. Various tools are implemented in ESCAPE to simulate information diffusion. Alerts can be transmitted through a network of sirens. In this case one can define location of these sirens and the distance covered by the microphone which is supposed to transmit the signal to the agents. Alerts and information can also be sent using radios or mobile devices, in this case the spatial dimension is less important than the individual equipment level and connection to

social networks which can be defined during the initialization process. Alerts and information can then be given to the entire population (siren, radio) or to sub-groups (cell broadcast principle).

Areas to be evacuated. The determination of the areas to be evacuated makes it possible to estimate the number of people who will have to be evacuated, independently or assisted by public transport. As for the environment definition, these areas to evacuate can be defined using a shapefile. Identification of these areas makes it possible to estimate whether it is necessary to carry out a poly-phased evacuation, by focusing at first on the evacuation of the people present in the most exposed zones. The choice between a simultaneous evacuation or an evacuation in phases can be then made on the basis of information related to hazard scenarios (differentiated levels of the hazard in the area, temporal dynamics of the hazard) or of a geographical division depending on criteria such as maximum population densities, building types, road network constraints etc. It finally helps to identify evacuation routes that minimize the risk of congestion. When an evacuation concerns many neighborhoods, care is taken, for example, to avoid the flow of vehicles crossing or converging towards the same exit point.

Gathering and orientation areas. Provisional shelters are places for hosting evacuees who do not have accommodation, such as family or friends. Each hosting site has a limited human capacity which must be known in order to allocate the population in the various shelters. For people with their own accommodation solution, orientation zones are targets that must be reached quickly during evacuation to exit the danger zone. These are most often roundabouts, motorway entrances or commercial areas that the most important roads converge to, thus facilitating the evacuation. From there, the vehicles disperse to reach various destinations outside the danger zone. The existence of these assembly points is generally accompanied by evacuation routes, a sub-section of the road network that the motorists will have to use, depending on their location, in order to leave the zone. These routes may be more or less adapted to the evacuation, with certain routes closed to traffic or traffic direction changed on others.

Public Transport Evacuation Plan. Public transportation is a resource deployed to collect non-autonomous people (children, elderly) and more generally anyone who does not have a means of transport to take them to the shelter or the orientation zone. We need to define pick-up points (bus stop) inside the zone for evacuation to shelters outside the area. Resources involved in terms of buses required and pick-up points depend on the proportion of non-autonomous population as defined in section Human and Household and their residence place. During the evacuation, the schedule file and normal routes are no longer adapted. Instead, we use evacuation routes (Noria), with pick-up and evacuation points and a pool of buses.

Human resource. Execution of a plan involves deploying human resources on the ground which will be able to secure danger-prone areas, install signposts on the ground, inform and help people during the evacuation process. ESCAPE provides two different methods to take such resources into account. The first one is to create agents in order to perform specific actions. These actions will then be limited by the number of agents available and their capacities to carry them out. Methods such as door-to-door information dissemination or road closure are available to these agents. The other option is to declare a value of available agents per hour and to compute, for every action taken in a given place, the necessary time to accomplish it and counting down the credit time.

After quoting the various resources available to the crisis manager, the following section details the use of these resources before and during the crisis.

Phase specification

The perception of an event (rising water level) can lead to an action (close) on a target (a road). Planning is about connecting perceptions with actions and targets in order to achieve a set of goals. These sets perception-action-targets can be broken down into various phases, from a vigilance phase to an alert one. A plan can then be described with the help of general semantics allowing each alert level to define perceptions that will trigger actions to be executed on a set of targets during the simulation. The overall plan is then supervised by one or more organizations that will be able to allocate resources for its execution.

Steps or phases of a plan. The phases of a plan relate to the pre-crisis, crisis and post-crisis periods. ESCAPE offers tools to model the first two phases, only the first one (preventive evacuation) or the second one (emergency evacuation). The procedures that allow the continuation of certain activities even in a degraded situation and the planning of the return of the populations are for the moment outside the scope of ESCAPE. From a time scale or threshold scale, the user can define as many phases that exist in a specific plan or create a new plan from scratch. It is possible to associate the time or threshold scale to a series of objects which will be used to both describe the hazard dynamics as well as engage in new protocols. The position of each object along the axis defines the time (or threshold) of its activation. These objects can represent probes (level of water), polygons (spread of flood), time (before event) or information (weather warning). The user, by changing the slider position on the scale, can decide the moment or the intensity at which the phase is switched on or off. Objects on this scale will then define the

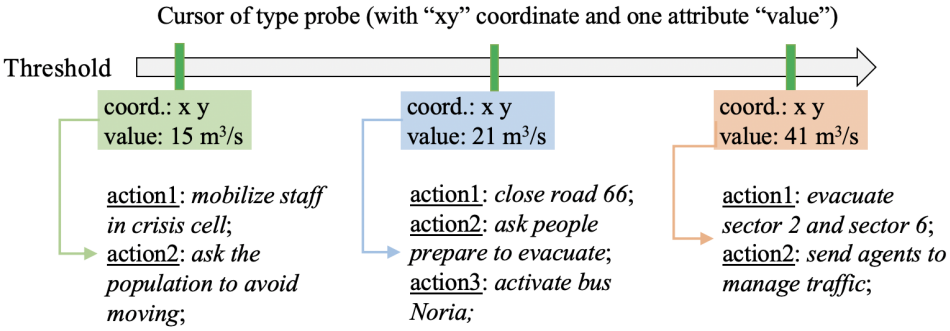


Figure 5. an example of scale of evolution of the hazard allowing to graduate the actions to lead

phases, such as *vigilance*, *pre-alert* and *alert* phases. Once the various phases are defined, it is necessary to define actions that can be taken for each of them (5).

Actions in a plan. An action, for example the closing of a bridge, is triggered by an organization either through direct access to the object concerned (here a link of the road network) or performed by an agent which must then have capabilities (perception, mobility, cognition etc.) to act on this object. An action can have a limited life, which must be defined in terms of phase, time or threshold. It can also have an unlimited life, which implies that once a phase is triggered, the initiated actions continue to be realized even if the thresholds progress and engage additional actions related to the subsequent phases. Many actions can be performed following the triggering of a phase. If initially these actions concern essentially the diffusion of information to the population and the agents involved in the plan, concrete actions such as closing of the schools or activation of Noria buses can follow. Gathering information on the evolution of a hazard or population dynamics is an action that can be performed throughout the simulation. Information can be collected either locally via probes or agents or globally via counters. Information here represents the mediated perception of an event. The second type of flow of information is related to information transmission. Resources such as communication devices can be used to transmit information to agents or other organizations. This information coming from the organization are inputs for other agents, whether it is individual agents of the population or organization agents (civil servants). The semantic content of sent messages is important because it will act on the action performed by the receiver. But a plan is not just about information flow but also about concrete actions. The main actions to be carried out in the implementation of an evacuation plan are possible here. Sending personnel to a specific area, closing / opening an object (e.g. a road section), modifying the attributes of an object (e.g. traffic light), triggering the dispatch of messages. The execution of most of these actions involves the use of the agents' elementary behaviors as described in figure 6.

After defining the risks in a given territory, the resources available and the strategies that can be implemented to protect populations, the last section describes the intelligence of the ESCAPE system.

Decision-Making Module

This cognitive module deals with individual aspects for perception, displacement, decision making or emotions related to citizens or civil servants and with organizational aspects for operationalization of the plans, adaptation to event dynamics and for optimization scenarios.

Agent cognition toward mobility behavior

Individual and collective response to unpredictable and potentially threatening circumstances due to a hazard event are difficult to observe and reproduce. However, there is a broad consensus on the complexity of human behavior during such an episode (Toledo et al. 2018). Hence, we want the agents of our framework to be able to mimic those responses and exhibit complex decision-making processes and behaviors. Our proposal extends the BDI model of cognition (Bratman 1987) to include emotional response and social attachment to better apprehend individual and collective dynamics during evacuation.

Enhanced Belief-Desire-Intentions architecture. In order to enable such complex human behaviors, ESCAPE allows the use of BEN (Behavior with Emotions and Norms) agent architecture (Bourgais et al. 2017). BEN is based on the BDI model of cognition that features modules for adding emotions, emotional contagion, personality, social relations and norms to agent behavior. It was already used to model human behaviors in two evacuation contexts: bush fire evacuation in Australia (Adam, Taillandier, et al. 2017) and the evacuation of the Station Night Club in the US (Valette et al. 2018). The use of BEN for ESCAPE enables not only taking into account the capacity of the

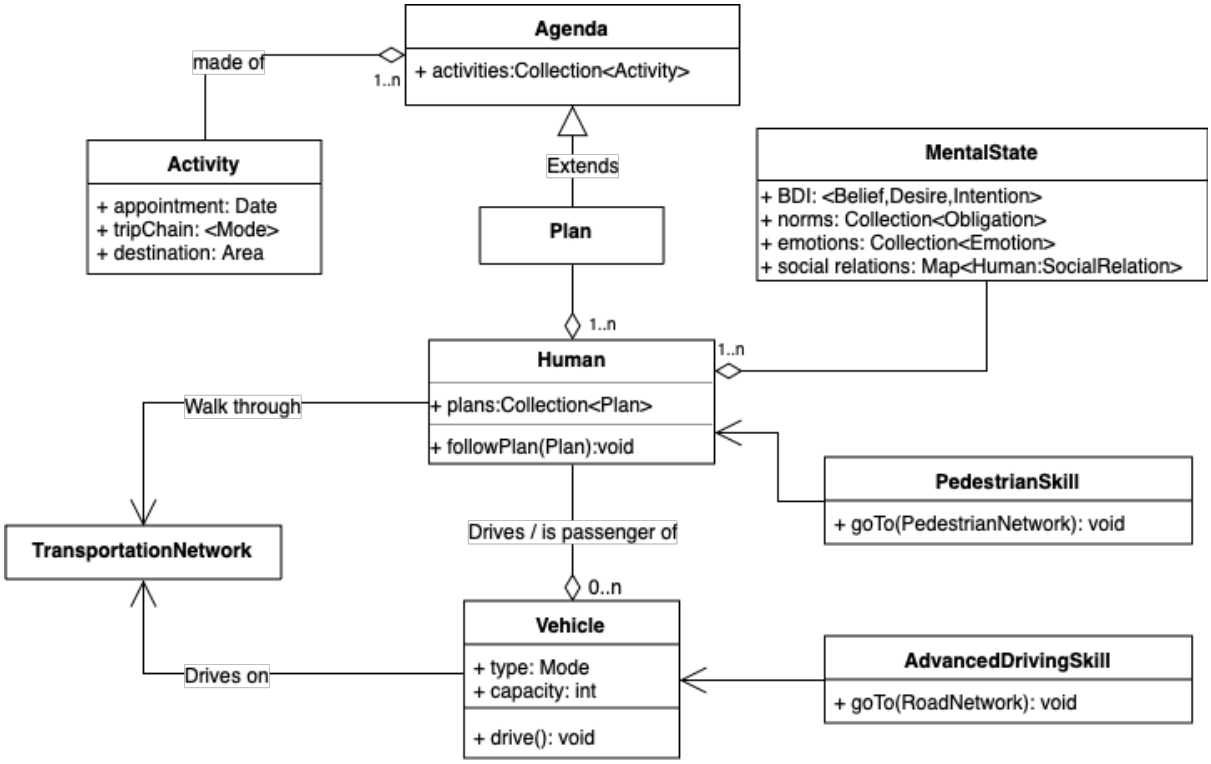


Figure 6. The UML class diagram of ESCAPE Human agent module

agents to carry out complex plans (*e.g.* choosing sub-objectives from a set of antagonist desires such as going to school to pick up their children and going as far as possible from the hazard area), but also the impact of emotions (and their contagion) and norms (laws, social norms) on the agent behavior. Not only can BEN be used to model the transition between normal behavior and evacuation behavior, using the knowledge of the disaster or danger signal, but the addition of norms, emotions and social relations also makes it possible to specify heterogeneous responses: for example, will drivers follow driving rules while feeling in danger or will parents go to the designated shelter while their children are at school? Moreover, the architecture is flexible enough to endorse normal as well as crisis behavior and decision-making circumstances. In addition to these cognitive aspects, the agent has skills related to its mobility.

Strategical, Tactical and Operational level. ESCAPE promotes an activity-based macro traffic dynamics using data-driven synthetic agenda to cope with the strategic level. Each individual of the synthetic population is generated with a scheduled set of activities according to its demographic attributes and optional data about mobility activities (see section Human and Household). Thus, the overall traffic demand is generated from the bottom-up, emerging from the agenda of individual users. The tactical level is more concerned with how the agent will cope with the direct environment in order to reach its destination. Using the BDI architecture coupled with emotions and social constraints (*i.e.* norms and social relationships) makes it possible to respond in a credible manner to unexpected traffic-related circumstances: for example, will they follow driving rules or will emotions and desires lead them to disregard them. The operational level is agentified using multi–modal algorithms to handle traffic related micro, *e.g.* lane change or collision avoidance, to nano dynamics, *e.g.* time frame speed regulations and continuous pedestrian walking direction. In the subsequent paragraphs, we will give details of the tactical and operational levels of pedestrian and motorized mobility behavior.

Human agent and mobility

Agent mobility includes pedestrian and motorized trips using private or public transport vehicles 6. Agents mostly follow a synthetic activity agenda as the main plan which is supposed to replicate daily mobility. In an emergency situation, depending on its perception by agents and the knowledge about safety measures, they can switch off more or less rapidly their synthetic agenda - they change their plans - to follow other targets: go back home, pick up children at school, reach an evacuation center ... and implement new means to achieve them: new trip, new modes of transport, all of this with a more or less strong emotional charge.

Pedestrian mobility model. Pedestrian mobility is a mix between free movement in a continuous space and a constrained path defined on a specific pedestrian network (Chapuis, Taillandier, Gaudou, et al. 2018). These interlacing dynamics make it possible to define the shortest path on a dedicated network and micro dynamics of continuous movement. On the tactical level, agents estimate the shortest path on the dedicated pedestrian virtual network, and, on the operational level, move over a continuous space following a series of nodes as intermediary goals. Each edge is then considered as a segment that occupied all the available space defined in the walking area, pedestrians going in and out as is the case in 1D road networks. Agents will avoid collision with other agents inside segments following a repulsion mechanism inspired by the social force model (SFM) (Helbing and Molnar 1995). Enhancements from the classical physical inspired model include behavioral and collective adaptation: the probability of agents getting back to a previous position when its current move inside a segment is blocked by other pedestrians and the collective speed adaptation negatively correlated (with threshold values) to the number of other users within the segment.

Vehicle mobility model. This model basically concerns motorized modes of transport, from individual to collective ones. The main idea is to dedicate a tactical level for *i.e.* path finding, re-routing and response to environmental change and to dedicate an operational level to *e.g.* lane change, speed or collision avoidance. The main processes of vehicle micro and nano dynamics are comprised within a *skill*, a set of methods (behavior) and variables (attributes) automatically associated to a kind of agent within the GAMA platform. This skill makes it possible for any vehicle (private car, bus) in ESCAPE to: manage moving speed, lane change, overtaking and distance from other users according to driving rules, road attributes and willingness of the driver. For more details on algorithms and processes involved in vehicle behavior, see Taillandier 2014 and Czura et al. 2015a. Note that both the use of personal vehicles and moving buses on a dedicated network as described in Transportation network and Area use the same library.

Evacuation behavior. While an agent will follow the agenda for day–to–day trips, *e.g.* go to work or go shopping, any hazard related event (siren, SMS, rumor etc.) can disrupt this normal course of action. In this transition stage, humans rarely remain fixed in one type of behavior but instead have a series of behavioral reactions, according a continuum between instinctive reactions such as stupefaction, panic, automaton behavior or instinctive struggle (Goya 2014) to reasoned reactions such as following the rules (confinement, evacuation), following the social norms (altruism) or individual rationality (pick the children up from school, fight against the potential impact of the danger). Deviant behaviors such as looting and curiosity can be ranked in this latter category (Cantin et al. 2016). In Escape, we then consider evacuation behavior as a different version of the agent's normal mobility behavior. The normal mobility behavior is then written in each agenda and each agent uses strategies and tactical behavior to follow this agenda. With hazard dynamics and / or the evacuation signal, agents may trigger another strategy. So, despite the danger, a certain part of the population will temporarily follow their every day life: this happens frequently in flood risk territory where, despite an alert level asking people to stay at home, the residents do not trust these authority signals and continue their normal activity, thus potentially endangering themselves (Ruin et al. 2017). On the contrary, others can react automatically to the event and the signal but do not follow any rule or advice given by the competent authorities: they will stay locked up at home instead of evacuating for example, or the opposite. Finally a proportion of people will both react in a timely manner to their own safety and follow the instructions that are given. It is the spatio-temporal conjunction of these three types of behavior that makes evacuation complex and which requires that it be organized and controlled.

Organization agent

Evacuation of hundreds of thousands of people is often based on an organization controlled by only a few dozen experts and guided on the ground by hundreds of agents. Human issues are therefore essential for the success of an evacuation, because people are expected to follow actions planned by experts, and organizations must be ready to adapt to people reactions and behaviors if dynamics fall outside the framework it has set. We make a distinction between and individual, as depicted previously with the citizens, and an organization. In the first category we also add those responsible for evacuation (civil servants: police, firefighters, civil defense, etc.). The second category represents an entity which aims to use resources in order to execute an evacuation plan as defined in Crisis Management. It is possible that an evacuation concerns several organizations if several plans exist. This may be so in the case of a major crisis spreading over a very large geographical area that involves several municipalities. In this case, one main organization can control the others with a specific plan and can collect and diffuse information about possible contradictions between actions taken by these different organizations. The behavior of an organization is then to use the information collected on the "ground" through control points and from other organizations to coordinate the evacuation plan. One can say that evacuation from the organization's point of view is a top-down approach.

The last section presents two case studies still undergoing active development. The aim of these two examples is to give some details about data processing, methods implemented and model evaluation.

ESCAPE CASE STUDIES

The first example shows the use of the driving skill in the context of the evacuation of a city with automobiles, the second one focuses on the evacuation of a district by pedestrians, access to motorized vehicles being impossible. Geographic data of these two case studies is loaded to define graphs from polyline geometries and polygons with related attributes (i.e. building, park, school ...).

Industrial accident in the French city of Rouen

Rouen is a Norman city (France) built across the river Seine, with six bridges over it. This topology makes its road network vulnerable to events that would damage or more generally reduce access to the bridges. Many SEVESO plants are installed along the banks of the river, most in reach of at least one bridge: industrial hazards are a preeminent risk for the city. The official instructions in the case of an industrial accident is the confinement of people, at home or in the nearest building. But if an event occurs during the day, tens of thousands of motorists or people on public transport may have to leave the dangerous area as quickly as possible due to lack of available shelter. How long can it take at best? Are the bridges that divide the city into two a real challenge for spontaneous evacuation? We built Rouen's road network with OSM data and chose to define as orientation zones all the nodes located at the border of the simulation space. These orientation zones represent targets that must be reached by drivers to evacuate the zone at risk. Bus lines and bus stop times are taken directly from the public site of the agglomeration's transport authority. Each stop is thus associated with a node in the graph and whenever necessary, in particular for the exclusive use of bus lanes, certain sections have been identified as being authorized for the buses only.

Figure 7. ESCAPE Rouen. Road network and buildings from OSM, with car (in green) and buses (in red)

Localization of the population is an important issue for this type of unpredictable hazard because it greatly affects its vulnerability. We have chosen as the initial condition the worst situation, that is to say, during the peak traffic time in the morning on a weekday. The volume of cars in circulation and their location on the network was estimated from the city's traffic count data. The driver's agenda was defined from the household and displacement survey, which indicates all the movements of a population sample for a typical day. Each agent localized in the network has an agenda indicating the places he must successively go to. Being in one place, he will implement different behaviors (tactical, strategical and operational as described in (Czura et al. 2015b)) to reach his next destination. The definition of the plan has only two phases here, since it goes from a normal circulation phase (Tranouez et al. 2009) to an accident phase (Daudé et al. 2009). In this case, all the agents receive the alert signal at the same time

and change their destination whatever be their agenda. For each of them, the new destination becomes the closest exit point of the network in terms of reaching time. Figure 7 shows a part of the simulation space. We can clearly see, in the center of the image, the 6 bridges that connect the right and the left banks of the city. Unsurprisingly, the city center with its 5 bridges is the longest to evacuate. According to initial conditions and parameters used (Czura et al. 2015b), it takes almost an hour and a half to evacuate most of the 42 000 vehicles present initially.

In these simulations, buses had the exclusive use of their dedicated lines and we did not simulate traffic accidents. The constraints on the use of the network can easily be relaxed by introducing in the plan, the use of a new network layer adapted to the evacuation, in which the bus lanes can be used by all vehicles, with possibly a change in the direction of circulation to promote centrifugal movements. The capacity of the model to allow integration or emergence of accident-prone situations is more complicated because of the several factors that may be involved in a traffic accident. For the moment, the mobility model corresponds to that of an autonomous car, capable of making rational decisions concerning its own objective (to reach a point as quickly as possible) while adapting itself to the behaviors of the other cars present in its environment. One might be tempted to use accident statistics on the territory to inject accident probabilities at certain accident-prone points. But we cannot be certain that it would be the same areas concerned and the same behaviors that would cause accidents during a crisis and evacuation situation.

Flood risk in a small quarter of Hanoi city

According to the world risk index, Vietnam is one of the 20 most vulnerable countries around the world with respect to natural disasters. The country's long coastline (covering more than 3400 km), the two major deltas (Red river and Mekong) and low altitude (only 20% of level land cover) make recurrent storm and typhoons deadly. On November 2017, Ho Chi Minh City authorities decided to evacuate by anticipation 2 million people because of the typhoon Damrey, nonetheless, causing at least 30 deaths. Management and control of such extreme and large events are a priority challenge for Vietnam's authorities.

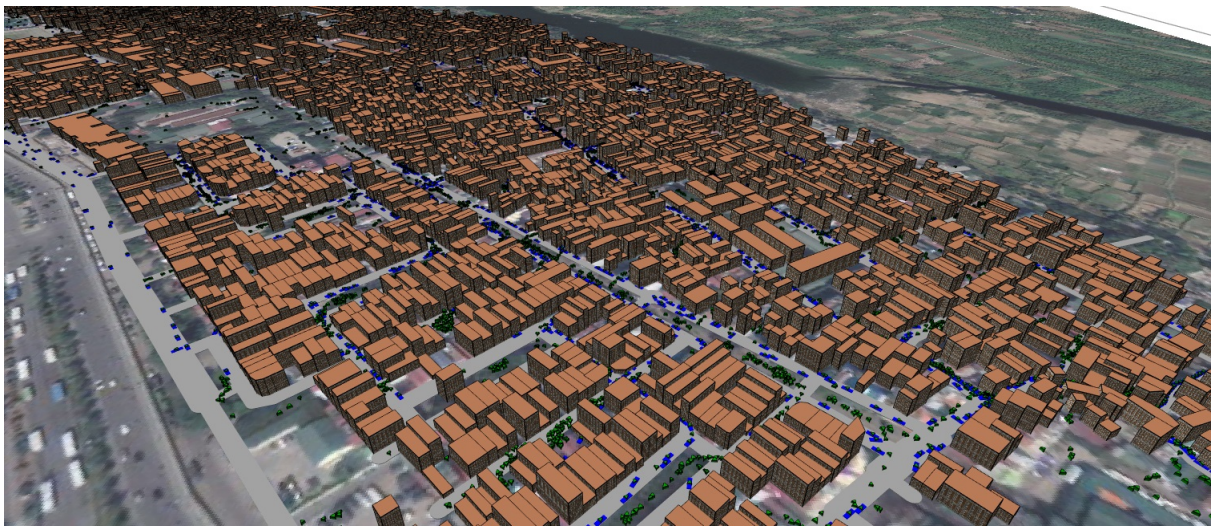


Figure 8. ESCAPE in Phuc Xa quarter in Hanoi. Evacuation model (Chapuis, Taillandier, Gaudou, et al. 2018) with both vehicle (in blue) and pedestrian (in green)

A previous study applied our framework to the small ward of Phuc Xa in Hanoi, the capital city of Vietnam (Chapuis, Taillandier, Gaudou, et al. 2018). It covers 1km^2 between the Old Quarter of Hanoi separated by a Dike and the Red River. The simulated scenario has been built in anticipation of a possible failure of the Hoa Binh dam, situated more than 80km upstream of Hanoi. The failure would cause a wave of water to submerge a large portion of the city, including Phuc Xa neighbourhood. Because of the lack of data, the hazard was not directly implemented into the simulation model. Rather, we chose to trigger dispatch of an evacuation signal to all the individuals of the studied population, urging them to evacuate the area towards the closest exit. Regarding the synthetic population of agents, we recreated the record population from available census of 2009: 15767 people with known age and gender.

Regarding mobility behavior, we implemented a basic every-day-life synthetic agenda as a proof of concept. Agents leave their home place to go to another building in the area at any random time between 8 and 10am. The target building represents either a known localized workplace and school for an active adult agent and under-18 agents respectively. A third kind of mobility, which mostly consists in wandering around, was implemented for retired

people. For mobility modes, we emphasize two-wheel vehicles and pedestrian mobility behavior. Agents will choose to use one or the other depending on the estimated travel time, without any consideration on whether they are moving towards everyday objectives or evacuation exits.

Much attention has been given to the micro-level mobility model: pedestrian movement is explicitly represented with avoidance of collision and walking over a continuous space, while two-wheel vehicles follow the rules defined in the previous study in the city of Rouen (see sections Human agent and mobility and Industrial hazard case study). For the former, the initial setup was defined using shapefiles of buildings and free walking areas. We applied Delaunay's triangulation algorithm to divide the whole space into small sections that allows pedestrian agents to find their way through the entire ward, while walking towards intermediary target points as is the case in a network.

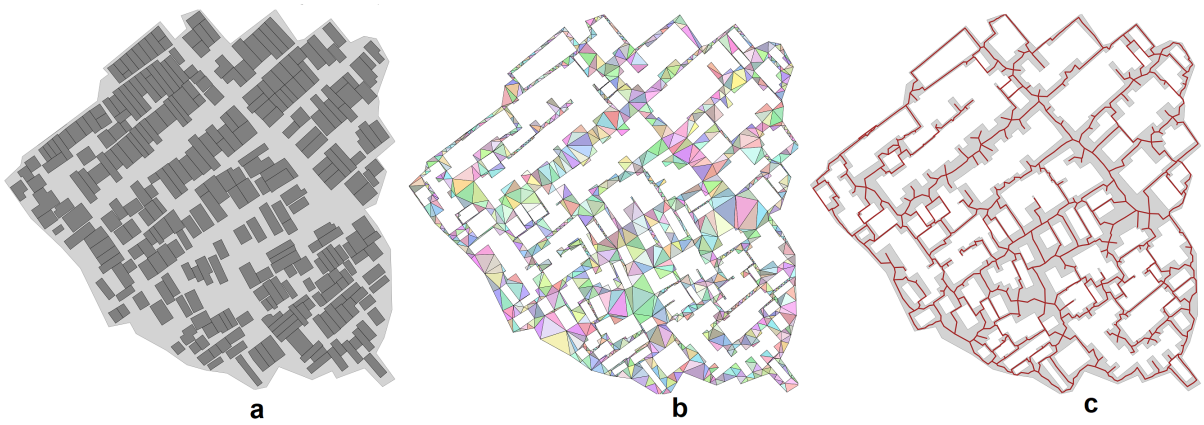


Figure 9. Small section of the ward with (a) walking area detection using buildings (b) Delaunay's triangulation process resulting in a scattered walking area (c) the final pedestrian virtual network to guide people walking through the area

As depicted in figures 9, defining the virtual network, in which the agents find their way to walk towards the destination, is a three-step process: (a) defining the walking area using any obstacle, in our case all the buildings (b) dividing the whole area into small sections to be used (c) eliciting the virtual network. Like vehicles, the agent will then be able to search for the shortest path from the starting point to the pedestrian destination using the network.

The evacuation signal is sent early in the morning at 8.00 am, with mobility behavior starting at 7.30 am. This means that some agents will be at home and others moving towards their goals as they walk or drive to their workplace, school or just wandering around. Thus, the evacuation starts while people are already in the middle of their daily activities. Considering this basic setup, we have been able to estimate the time of evacuation for the overall area to be about 1 hour 37 minutes. However, because of lack of data, we have not been able to apply any kind of mitigation strategy, nor different scenarios considering the impact of the hazard on the evacuation process.

CONCLUSION AND FUTURE WORKS

This paper is about a new multi agent-based simulation framework named ESCAPE, which aims to support a wide range of population evacuations in urbanized territories. As such, ESCAPE can clearly be categorized as a decision-making tool. It can take into account both the fine geographic scale, *e.g.* nano-scale traffic and continuous movement as well as the fine time scale, *e.g.* second-to second speed regulation. It is built upon the GAMA environment and organized around four main modules:

- the **Environment** module deals with the spatial and demographic description of the simulation domain;
- the **Hazard** module describes all the characteristics of catastrophic events and the associated impact on human agents and infrastructures;
- the **Decision-Making** module focuses on the behavior and cognitive processes of people affected by the hazards and organizations attempting to manage the evacuation;
- the **Crisis management** module provides available resources and plan to guide and coordinate human and organizational agent responses;

The framework already integrates dedicated tools to provide modelers an easy-to-use environment to simulate evacuation in urbanized areas. However, the integration process is still a work-in-progress and we plan to release the first beta version in 2019. As shown in previous case studies, at the current stage, the framework makes it possible to simulate the evacuation of a city using multi–modal traffic model. The next phase will be to implement evacuation plans and organization to manage them, in order to simulate evacuation strategies. This will take the form of *how-to* and *what-if* scenario. Indeed, one essential aspect of studying evacuation through simulation is the possibility of testing several strategies and assess how they succeed and compare the output. To this end, we propose several default indicators like time of evacuation and the number of exposed agents. But our perspective is to give modelers tools to build their own indicators, so that they can adapt what success is and how they can asses it to the type of hazard (and exposure), the kind of safe area or any other evacuation circumstances. A typical *What-if?* scenario in ESCAPE is to replay the same simulation and then to disrupt an element, either of the plan (no activation of an action) or of the environment (faulty probe or blocking of a section). An optimization scenario *How-to?* in ESCAPE can calculate routes that minimize the evacuation time of a group of people located in different areas to gathering and regrouping areas. The classical Dijkstra algorithm can be used as a preliminary approximation in order to build an evacuation plan, which will then be evaluated through simulations.

Acknowledgment This work is funded by the ANR ESCAPE project, grant ANR-16-CE39-0011-01 of the French Agence Nationale de la Recherche and by the MADNESS project, grant HN0002110 of the Normandie Region and European Union (FEDER).

REFERENCES

Adam, C. and Gaudou, B. (2017). "Modelling Human Behaviours in Disasters from Interviews: Application to Melbourne Bushfires". In: *Journal of Artificial Societies and Social Simulation* 20.3, p. 12.

Adam, C., Taillandier, P., Dugdale, J., and Gaudou, B. (2017). "BDI vs FSM Agents in Social Simulations for Raising Awareness in Disasters: A Case Study in Melbourne Bushfires". In: *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)* 9.1, pp. 27–44.

Afzal, M., Ranjitkar, P., Costello, S. B., Jayananthan, N., and Jayasinghe, S. (2017). "Emergency Evacuation Modelling using Traffic Simulation: A Case Study of Auckland". en. In: p. 13.

Bañgate, J., Dugdale, J., Adam, C., and Beck, E. (2017). "A review on the influence of social attachment on human mobility during crises". In: *ISCRAM, Albi*.

Banos, A., Corson, N., Lang, C., Marilleau, N., and Taillandier, P. (2017). "Multiscale modeling: Application to traffic flow". In: *Agent-based Spatial Simulation with NetLogo, Volume 2*. Elsevier, pp. 37–62.

Beck, E., Dugdale, J., Truong, H. V., Adam, C., and Colbeau-Justin, L. (2014). "Crisis Mobility of Pedestrians: From Survey to Modelling, Lessons from Lebanon and Argentina". en. In: *ISCRAM-Med*. LNBIP. Springer, Cham, pp. 57–70.

Bourgais, M., Taillandier, P., and Vercouter, L. (2017). "Enhancing the behavior of agents in social simulations with emotions and social relations". In: *International Workshop on Multi-Agent Systems and Agent-Based Simulation*. Springer, pp. 89–104.

Bratman, M. (1987). "Intentions, plans, and practical reason." In: *Harvard Univ. Press*.

Cantin, G., Verdière, N., Lanza, V., Aziz-Alaoui, M. A., Charrier, R., Bertelle, C., Provitolo, D., and Dubos-Paillard, E. (2016). "Mathematical Modeling of Human Behaviors During Catastrophic Events: Stability and Bifurcations". In: *I. J. Bifurcation and Chaos* 26.10, pp. 1–20.

Cebeillac, A., Daudé, É., and Huraux, T. (2017). "Where ? When ? And how often ? What can we learn about daily urban mobilities from Twitter data and Google POIs in Bangkok (Thailand) and which perspectives for dengue studies ?" en. In: *Netcom* 31-3/4, pp. 283–308.

Chalaris, M., Emmanouloudis, D., and Wen, J.-C. (2018). *Novel approaches in risk, crisis and disaster management*. Natural Di. Nova Science Pub, p. 428.

Chapuis, K., Taillandier, P., Gaudou, B., Drogoul, A., and Daude, E. (2018). "A multi-modal urban traffic agent-based framework to study individual response to catastrophic events". en. In: *The 21st International Conference on Principles and Practice of Multi-Agent Systems (PRIMA2018)*, p. 8.

Chapuis, K., Taillandier, P., Misslin, R., and Drogoul, A. (2018). "Gen*: a generic toolkit to generate spatially explicit synthetic populations". In: *International Journal of Geographical Information Science* 32.6, pp. 1194–1210.

Chen, X. and Zhan, F. B. (2008). "Agent-based modelling and simulation of urban evacuation: relative effectiveness of simultaneous and staged evacuation strategies". en. In: *Journal of the Operational Research Society* 59.1, pp. 25–33.

Czura, G., Taillandier, P., Tranouez, P., and Daudé, É. (2015a). "MOSAIIC: City-Level Agent-Based Traffic Simulation Adapted to Emergency Situations". In: *Proceedings of the International Conference on Social Modeling and Simulation, plus Econophysics Colloquium 2014*. Ed. by H. Takayasu, N. Ito, I. Noda, and M. Takayasu. Cham: Springer International Publishing, pp. 265–274.

Czura, G., Taillandier, P., Tranouez, P., and Daudé, É. (2015b). "MOSAIIC: City-Level Agent-Based Traffic Simulation Adapted to Emergency Situations". In: *Proceedings of the International Conference on Social Modeling and Simulation, plus Econophysics Colloquium*. Ed. by Springer. Proceedings in Complexity. Chap. 24, pp. 265–274.

Daudé, É. (2008). "Multi-agent systems for simulation in Geography: Moving towards an artificial Geography". In: *The modeling process in Geography: From determinism to complexity*. Ed. by Y. Guermond. ISTE&WILEY. London: GIS Series. Chap. 13, pp. 309–329.

Daudé, É., Tranouez, P., and Langlois, P. (2009). "A multiagent urban traffic simulation. Part II: dealing with the extraordinary". In: *Internation Conference on Complex Systems and Applications*, pp. 1–5.

Flötteröd, Y.-P. and Erdmann, J. (2018). "Dynamic Reroute Modeling for Emergency Evacuation: Case Study of Brunswick City, Germany". In: *Int. Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering* 12.4, pp. 99–109.

Goya, M. (2014). *Sous le feu: la mort comme hypothèse de travail*. Tallandier.

Grignard, A., Taillandier, P., Gaudou, B., Vo, D. A., Huynh, N. Q., and Drogoul, A. (2013). "GAMA 1.6: Advancing the Art of Complex Agent-Based Modeling and Simulation". In: *PRIMA 2013*. Ed. by G. Boella, E. Elkind, B. T. R. Savarimuthu, F. Dignum, and M. K. Purvis. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 117–131.

Harten, E., Patel, R., Ryan, L., Sawyer, J., Barbera, J., Mazzuchi, T., and Santos, J. (2018). "Evaluation of traffic mitigation strategies for pre-hurricane emergency evacuations". en. In: *2018 Systems and Information Engineering Design Symposium (SIEDS)*. Charlottesville, VA: IEEE, pp. 214–219.

Hawe, G. I., Coates, G., Wilson, D. T., and Crouch, R. S. (2012). "Agent-based simulation for large-scale emergency response: A survey of usage and implementation". en. In: *ACM Computing Surveys* 45.1, pp. 1–51.

Helbing, D. and Molnar, P. (1995). "Social Force Model for Pedestrian Dynamics". In: *Physical Review E* 51.5, pp. 4282–4286.

Kim, J., Lee, S., and Lee, S. (2017). "An evacuation route choice model based on multi-agent simulation in order to prepare Tsunami disasters". In: *Transportmetrica B: Transport Dynamics* 5.4, pp. 385–401.

Knabb, R., Brown, D., and Rhome, J. (2006). *Tropical Cyclone Report: Hurricane Rita 18-26 sept. 2005*. Tech. rep. 1. National Hurricane Center, pp. 1–33.

Kujala, R., Weckström, C., Darst, R. K., Mladenović, M. N., and Saramäki, J. (2018). "A collection of public transport network data sets for 25 cities". In: *Scientific data* 5, p. 180089.

Lämmel, G., Klügl, F., and Nagel, K. (2009). "The MATSim Network Flow Model for Traffic Simulation Adapted to Large-Scale Emergency Egress and an Application to the Evacuation of the Indonesian City of Padang in Case of a Tsunami Warning". en. In: *Pedestrian behavior: models, data collection and applications*. Ed. by H. Timmermans. 1. ed. Bingley: Emerald.

Luo, F., Cao, G., Mulligan, K., and Li, X. (2016). "Explore spatiotemporal and demographic characteristics of human mobility via Twitter: A case study of Chicago". en. In: *Applied Geography* 70, pp. 11–25.

Müller, K. and Axhausen, K. W. (2010). *Population synthesis for microsimulation: State of the art*. ETH Zürich, Institut für Verkehrsplanung, Transporttechnik, Strassen-und Eisenbahnbau (IVT).

Perrow, C. (2007). *The Next Catastrophe: Reducing Our Vulnerabilities to Natural, Industrial, and Terrorist Disasters*. Princeton University Press.

Ruin, I., Lutoff, C., and Shabou, S. (2017). "Anticipating or Coping: Behaviors in the Face of Flash Floods". In: *Floods*, pp. 259–275.

Taillandier, P. (2014). "Traffic simulation with the GAMA platform". In: *International Workshop on Agents in Traffic and Transportation*. France, 8 p.

Taillandier, P., Gaudou, B., Grignard, A., Huynh, Q.-N., Marilleau, N., Caillou, P., Philippon, D., and Drogoul, A. (2018). "Building, composing and experimenting complex spatial models with the GAMA platform". In: *GeoInformatica*.

Toledo, T., Marom, I., Grimberg, E., and Bekhor, S. (2018). "Analysis of evacuation behavior in a wildfire event". In: *International Journal of Disaster Risk Reduction*.

Tranouez, P., Langlois, P., and Daudé, É. (2009). "A multiagent urban traffic simulation. Part I: dealing with the ordinary". In: *Internation Conference on Complex Systems and Applications*, pp. 297–302.

Valette, M., Gaudou, B., Longin, D., and Taillandier, P. (2018). "Modeling a Real-Case Situation of Egress Using BDI Agents with Emotions and Social Skills". In: *International Conference on Principles and Practice of Multi-Agent Systems*. Springer, pp. 3–18.

Wang, H., Mostafizi, A., Cramer, L. A., Cox, D., and Park, H. (2016). "An agent-based model of a multimodal near-field tsunami evacuation: Decision-making and life safety". en. In: *Transportation Research Part C: Emerging Technologies* 64, pp. 86–100.

Zhu, Y., Xie, K., Ozbay, K., and Yang, H. (2018). "Hurricane Evacuation Modeling Using Behavior Models and Scenario-Driven Agent-based Simulations". en. In: *Procedia Computer Science* 130, pp. 836–843.

Zucker, J.-D., Drogoul, A., and Treuil, J.-P. (2008). *Modélisation et simulation à base d'agents*. Ed. by Dunod, p. 352.

Assessing Flood Recovery of Small Businesses using Agent-Based Modelling and Simulation

Meshal Alharbi
Durham University
meshal.g.alharbi@durham.ac.uk

Graham Coates
Newcastle University
graham.coates1@newcastle.ac.uk

ABSTRACT

In developed countries, small and medium-sized enterprises (SMEs) represent the majority of all businesses, e.g. 99.9% in the UK. Given this significant proportion, any disruption to the operation of SMEs will have a negative impact on a nation's economy. In the context of flooding, this paper reports on the use of agent-based modelling and simulation (ABMS) to assess SMEs immediate response and short-term recovery. In particular, it focuses on the interactions between manufacturing SMEs and mutual aid partners, and retail SMEs and companies specializing in refurbishing premises. Results show that a manufacturing SME with a mutual aid partner can reduce loss in production by approximately 6% over a 7 working day period. In relation to retail SMEs, those with employees able to be allocated to refurbish its premises recovered faster than SMEs employing a refurbishment company, potentially one day earlier.

Keywords

SMEs; agent-based modelling and simulation; flooding; short-term recovery; manufacturing and retail.

INTRODUCTION

Disruption caused by flooding to small and medium-sized enterprises (SMEs) can result in a significant impact on a nation's economy (Coates et al., 2014). For instance, the UK's 2007 summer floods had an estimated 2.3 billion of total economic costs (Chatterton et al., 2010). A considerable portion of these losses affected SMEs which they represent 99.9% of all UK businesses (Rhodes, 2015). The term SME indicates a business with a given number of employees that differs based on the country of origin (Hallberg, 1999). The upper limit is 250 employees in the UK (Lukács, 2005) while the number increases to 500 employees in the United States (Ayyagari et al., 2003).

SMEs are often at high risk of flooding and other natural hazards (Crichton, 2008; Wedawatta et al., 2010). Also, SMEs usually have limited resources in terms of manpower and finance (Omar & Fraser, 2010; Sullivan-Taylor & Branicki, 2011; Van Gils, 2005), and tend to lack organisational disaster mitigation plans (Jones & Ingirige, 2008; Li et al., 2015). Thus, due to the importance of this proportion of businesses to a developed nation's economy, this paper aims to assess small manufacturing and retail businesses immediate response and short-term recovery from flooding. More specifically, the paper examines mutual aid partner's effect on manufacturing SMEs recovery and the effect of refurbishment companies' on the recovery of retail SMEs. According to Stier and Goodman (2007), mutual aid is defined as the sharing of suppliers, equipment, personal information, or other resources between two parties. Also, it is indicated that mutual aid is useful when local resources are insufficient to meet a business needs due to the disaster that has occurred (Sutton & Tierney, 2006). Furthermore, businesses are encouraged to improve their disaster response through contracts and mutual aid agreements. However, mutual aid agreements can be limited in scope, in which it is impossible to anticipate every eventuality (British Columbia, 2014).

Simulation models, such as agent-based models (ABM), have become a common tool in many disciplines for solving complex systems created of autonomous entities (Grimm et al., 2006). Agent-based modelling and simulation (ABMS) represents a powerful analytical research tool that can be used to investigate complex

processes (Shim et al., 2017). ABMS is commonly recognized as an effective tool for solving complex problems in business and social science (Dignum & Tick, 2007; Gilbert & Terna, 2000; North & Macal, 2007; Prasad & Chartier, 1999). Agents can be defined as an entity acting within a virtual environment that act based on predefined rules (Labarthe et al., 2007; Macal & North, 2010). Autonomous agents can be modelled to represent individuals or organisations with a set of attributes to personalize them, and rules to regulate their interactions with the other agents within their environment (Macal & North, 2010). In relation to ABMs' specifications, Helbing (2012) stated that the interaction network must be defined. Also, the initial values of all variable and the boundary conditions should be determined in advanced.

ABMS is used in this research in order to represent the large number of SMEs, each with a set of attributes and behaviours, which interact with related organisations. The approach involves interactions between SMEs and related organisations such as suppliers, customers, electrical contractors, plumbing contractors, IT service providers, refurbishment companies, mutual aid partners, Environment Agency, cleaning service providers, and insurance companies. Each of these types of related organisations provides SMEs with assistance or a service to support their post-flood recovery.

Contribution of this paper

The agent-based modelling and simulation reported in this paper focuses on the recovery of manufacturing and retail SMEs from a severe flood event in Tewkesbury, UK. Further, it reports on the interactions between SMEs and ten different SME-related organisations (suppliers, customers, electrical contractors, plumber contractors, IT service contractors, cleaning service providers, Environment Agency, mutual aid partners, refurbishment companies, insurance companies). However, the paper focuses on presenting only the interactions between (a) manufacturing SMEs and mutual aid partners, and (b) retail SMEs and companies specializing in refurbishing premises; although other SME-related organisations are modelled. Also, for manufacturing SMEs, their recovery has been assessed by making use of the trapezoidal rule to establish the level of production loss due to the flood event.

AGENT-BASED MODELLING AND SIMULATION APPROACH

An agent-based model has been developed and used in simulations to assess the potential effects on SMEs' immediate response to, and short-term recovery from, flooding of a range of precautionary measures deployed in the manufacturing and retail sectors. In this research, the ABMS approach is made up of three main components as indicated in Figure 1: (i) flood-event simulation; (ii) a modelled geographical environment (MGE); (iii) agent-based modelling and simulation. Firstly, flood event simulation represents the input data (e.g. inundation data) that feeds into the MGE component. Next, the MGE combines Ordnance Survey (OS) data (e.g. Topography, Integrated Transport Network (ITN), and AddressBase Plus layers) with the input from the flood event simulation to enable the identification of the flooded and non-flooded organisations. Consequently, the identified organisations, including flooded and non-flooded SMEs in addition to related organisations, are modelled as autonomous agents and simulated over three time frames: pre-flood, during flood, and post-flood.

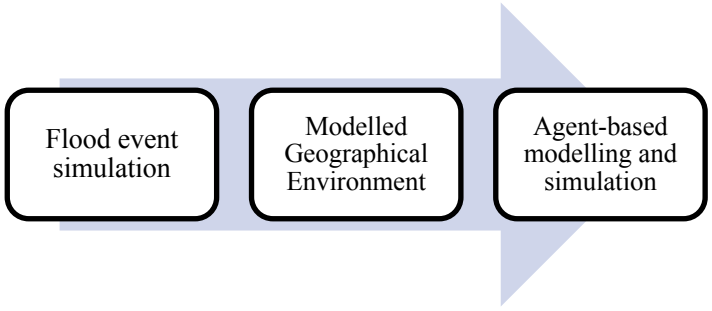


Figure 1. ABMS Approach Overview

MODELLING SMES FROM THE MANUFACTURING AND RETAIL SECTORS

Overview

Manufacturing and retail SMEs are modelled as autonomous agents with a different set of attributes, behaviours, and predefined precautionary measures. Behaviours, along with their typical durations, attributes and precautionary measures were established from various sources: (i) semi-structured interview transcripts with

SMEs having experience of flooding or being at risk of flooding; (ii) EA guidance; (iii) academic literature.

Attributes can be static (e.g. business name, size, and location) or dynamic (e.g. power available and the number of employees at a premises). SMEs' behaviours can be carried out in the pre- and/or post-flood period as discussed in (Alharbi & Coates, 2017, 2018). These behaviours are classified in terms of their type (e.g. generic or specific), priority execution order, required number of employees (e.g. single or multiple) required to enact them; pre-flood behaviours are as indicated in Figure 2. Further, each of these behaviours has a duration range obtained from transcripts of semi-structured interviews with SMEs, which introduces a degree of stochasticity into the model.

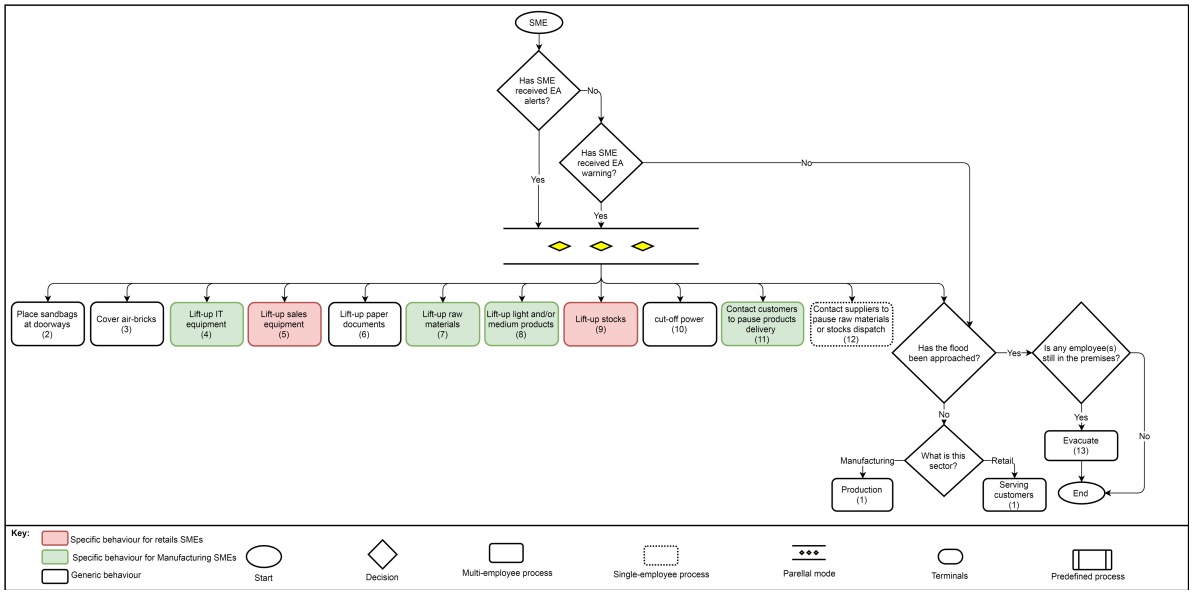


Figure 2. Pre-Flood Behaviours

In Figure 2, all the possible SMEs' pre-flood behaviours for both sectors are presented along with their associated priority execution order. Also, as shown in Figure 2, the colour used to represent pre-flood behaviours signifies the type of SME sector: green for the manufacturing sector; red for the retail sector; white for both sectors.

In relation to SMEs' precautionary measures, these are implemented by businesses prior to a flood event taking place and are intended to: (i) prevent or reduce water entering an SME's premises (e.g. build bund wall) or (ii) remove the need for, or reduce the duration of, some behaviours (e.g. raise the location at which raw materials/stock are stored).

Manufacturing SMEs

Manufacturing businesses represent a key component of developed countries' economies (Haraguchi et al., 2017). In the UK, manufacturing SMEs account for 5% of businesses, 10% of employment, and 15% of economic turnover (Rhodes, 2015). Manufacturing SMEs are modelled with the following dynamic attributes: raw materials (*RM*), production machines (*M*), employees (*E*) and power (*P*). These attributes vary during the course of a simulation and contribute directly to the SMEs' performance, i.e. production level *(PL)*. At each simulation tick, (a) production level and (b) raw materials available at the next simulation tick are both determined. If the amount of raw materials available at the current tick $\mathrm{RM_t} \geq \min\{\mathrm{E_p}, \mathrm{M}\}$, then both (a) and (b) are determined as follows:

$$\mathrm{PL} = \min\{\mathrm{E_p}, \mathrm{M}\} \times 100 \quad (1)$$

$$\mathrm{RM_{t+1}} = \mathrm{RM_t} - \min\{\mathrm{E_p}, \mathrm{M}\} \quad (2)$$

In equations (1) and (2), both (a) and (b) are determined according to the relationship between (i) the ratio of production employees working on production, $\mathrm{E_p^p}$, to total number of production employees, $\mathrm{E_t^p}$, and (ii) the ratio of machines available, $\mathrm{M_a}$, to total number of machines, $\mathrm{M_t}$. However, if the amount of raw materials available at the current tick $\mathrm{RM_t} < \min\{\mathrm{E_p}, \mathrm{M}\}$, then the production level is determined according to the amount of raw materials available at the current tick as follows:

$$\mathrm{PL} = \mathrm{RM_t} < \min\left\{\mathrm{E_p}, \mathrm{M}\right\} \quad (3)$$

$$\mathrm{RM_{t+1}} = 0 \quad (4)$$

In addition to these attributes, manufacturing SMEs are modelled with a different set of generic and manufacturer specific behaviours along with a set of precautionary measures (e.g. raise the location at which machines are placed), which may be implemented by an SME prior to a flood event occurring. These behaviours and attributes have been identified from a series of semi-structured interviews with SMEs involved in flood-related events and/or are located in flood-prone areas. Details of the attributes and behaviours of manufacturing SMEs are provided in (Alharbi & Coates, 2017, 2018).

Retail SMEs

The retail sector refers to the wholesale and retail sale of any type of goods or their associated services (United Nations, 2008). In the UK, retail businesses account for 33% of turnover and 19% of employment (Rhodes, 2015). Furthermore, it has been reported that the retail sector is among the largest job creators in the UK (Omar & Fraser, 2010). In this research, retail SMEs are modelled as agents along with their pre-defined static attributes (e.g. name and size) and dynamic attributes - power (*P*), stock (*S*), sales equipment (*SE*), and employees (*E*), and environment condition (*EC*) - along with a different set of precautionary measures.

In terms of the dynamic attributes, the relationship between them is presented in Figure 3, demonstrating that the availability of each is necessary for service capability, i.e. the capability to offer a service to customers.

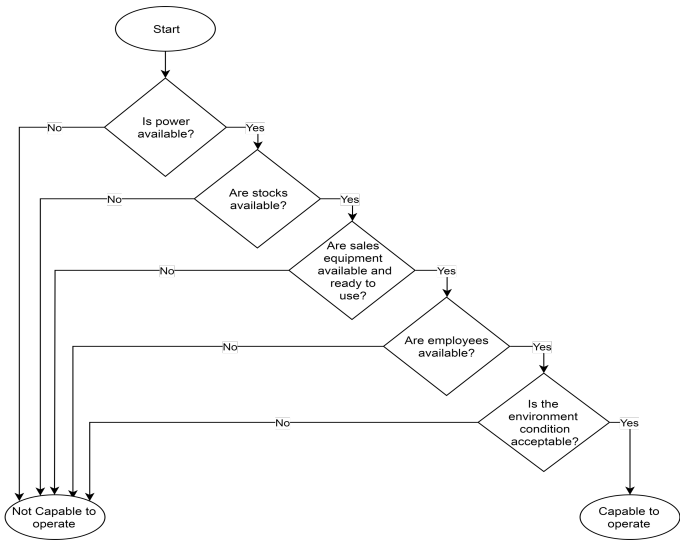


Figure 3. Retail Dynamic Attributes Relationships

As mentioned previously, these dynamic attributes may change during a simulation and contribute directly to a retail SMEs' performance, which is measured as the service capability level (*SC*). The flood event is simulated at 30-minute intervals, each of which corresponds to 1 simulation time step or tick (t_s); the service capability is determined at each half hour interval (or tick) throughout the simulated period. Post-flood, a flood-affected retail SME's service capability can be resumed if:

(a) the power supply is restored to the premises, i.e. $P = 1$ ($P = 0$ indicates that a retail SME's premises has no power and thus it is unable to operate), and
(b) stock is available, $S > 0$, where S is the percentage of stock available in its premises, and
(c) sales equipment is available, $SE > 0$, where SE is the percentage of an SME's available sales equipment, and
(d) employees are available, $E > 0$, where E is the percentage of an SME's employees available to work, and
(e) environment conditions are acceptable, $EC > 80\%$, where EC is the percentage of the work environment conditions are in a state suitable for the SME to operate.

In relation to (c), sales equipment is replaced if damaged. Replacing damaged equipment affects the recovery profile, prompting retail SMEs' status to be either in recovery, i.e. $SC = 0\%$, or fully recovered, i.e. $SC = 100\%$, providing the other dynamic attributes are greater than zero. For the environment conditions (EC), a value of

80% was selected signifying that if 80% of the premises was refurbished to an acceptable state making it possible for customers to visit the premises then the retail SME could operate, if the other dynamic attributes are greater than zero.

SME RELATED-ORGANISATIONS

SME related-organisations, which may include other businesses, can interact with SMEs to provide assistance or a service, such as electricity repairs, to support their recovery. These organisations include electrical contractors, plumbing contactors, cleaning service providers, and IT service contractors; these are modelled as either regional or national. On request, regional organisations arrive quickly at an SME's premises, but are limited in terms of numbers. In contrast, national organisations are likely to arrive later than the regional service providers, but are greater in number. For cleaning service providers, they could have a pre-defined contract with insurance companies to provide such a service to insured SMEs if required. Thus, a cleaning service could be interrupted while working for a non-contracted SME at any time when it is contacted by an insurance company with which it has a pre-defined contract. In this case, the affected non-contracted SME would need to contact another service provider; otherwise its employees may need to be allocated to clean up. In terms of suppliers and customers, a supplier provides manufacturing and retail SMEs with raw materials and stock respectively, at regular intervals, e.g., daily, every three days, weekly, or every two weeks. For manufacturing SMEs, customers take delivery on a daily or weekly basis based on the type of products, daily if light products whereas medium and heavy products are delivered weekly.

As shown in Figure 4, manufacturing and retail SMEs can interact with electrical contractors, plumbing contractors, the Environment Agency (EA), suppliers, customers, cleaning service providers, and insurance companies. In addition, manufacturing SMEs can interact with IT service contractors and mutual aid partners, whereas retail SMEs can interact with refurbishment companies. While a cleaning service can be provided to both manufacturing and retail SMEs, refurbishment occurs only in retail SMEs. This refurbishment behaviour refers mainly to renovation and redecoration of retail SMEs' premises

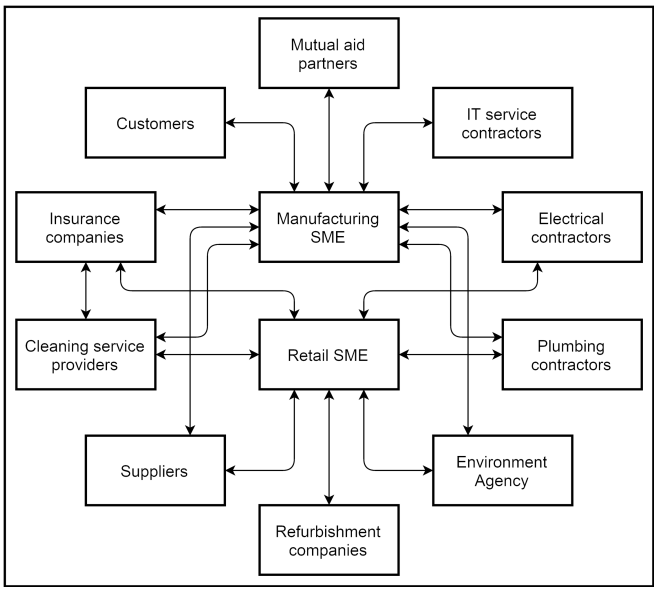
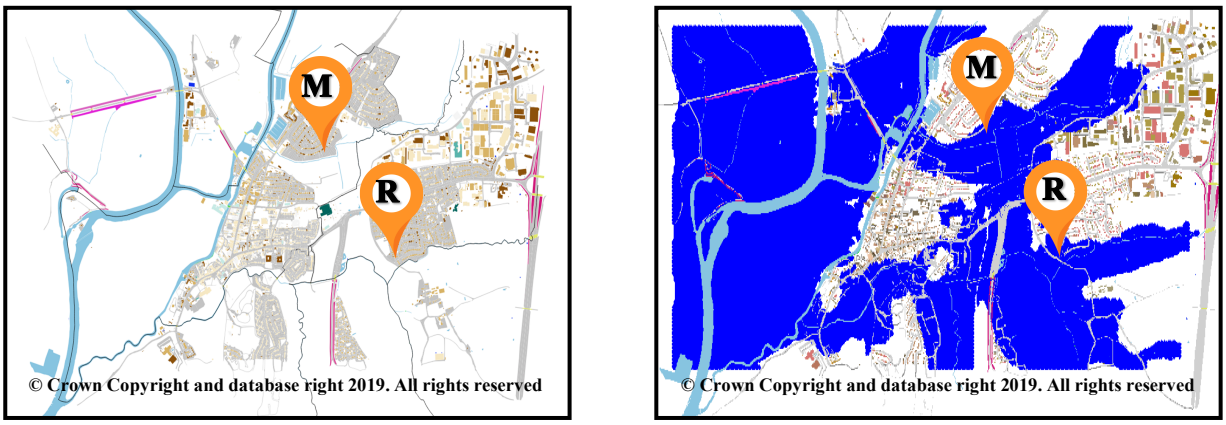


Figure 4. Interactions between SMEs and Related-Organisations

AGENT-BASED SIMULATIONS

Case Study

The case study presented in this paper is related to the 2007 severe flood event in Tewkesbury, UK. This geographical area was considered due to the high water levels reached, which significantly impacted homes and businesses. According to Tewkesbury Borough Council, more than 1800 houses and 300 businesses were flooded (Tewkesbury Borough Council, 2018). In Figure 5, the locations of two micro-sized businesses of the 349 modelled, labelled 'M' and 'R' for an SME from the manufacturing and retails sector respectively, are identified in (a) before the flood occurs and (b) after 3 days of rainfall.



(a) Tewkesbury Before Flood **(b) Tewkesbury After 3 Days of Rainfall**

Figure 5. Case study area: Tewkesbury

The flood event simulation generated inundation data representing the water depth throughout the area selected modelled at 30-minute intervals over a 318.5-hour period. After coupling the OS data, including the AddressBase Plus layer, with the inundation data, a total of 920 organisations were identified in the area under consideration with 207 of them flooded at some point during the 318.5 hours simulated. Table 1 presents a breakdown of these organisations according to the International Standard Industrial Classification of all Economic Activities (ISIC) (United Nations, 2008).

Table 1. Organisations in Tewkesbury

ISIC	Organisations		
	Flooded	Not flooded	Total
Administrative services	10	39	49
Accommodation services	8	30	38
Agriculture/forestry/fishing	1	2	3
Arts and entertainment	5	11	16
Education	0	5	5
Electricity/gas/steam	1	2	3
Finance	0	6	6
Construction	1	3	4
Human health / social work	7	100	107
Information/communication	0	8	8
Manufacturing	16	107	123
Mining and quarrying	0	3	3
Other service activities	4	29	33
Professional services	0	3	3
Public administration	8	16	24
Retail	4	222	226
Transportation and storage	92	118	210
Water	50	9	59
Total	**207**	**713**	**920**

According to statistical data related to businesses in the UK, 99.9% of all businesses are SMEs with 96%, 3.3% and 0.6% being categorised as micro-, small- and medium-sized respectively (White, 2016). Thus, the flooded manufacturing and retail businesses are modelled (see Figure 6) in these proportions given a random number of employees generated for every SME corresponding to their respective size. That is, a micro-sized business has 1 to 9 employees, a small business has 10 to 49, and a medium-sized business has 50 to 249 (White, 2016).

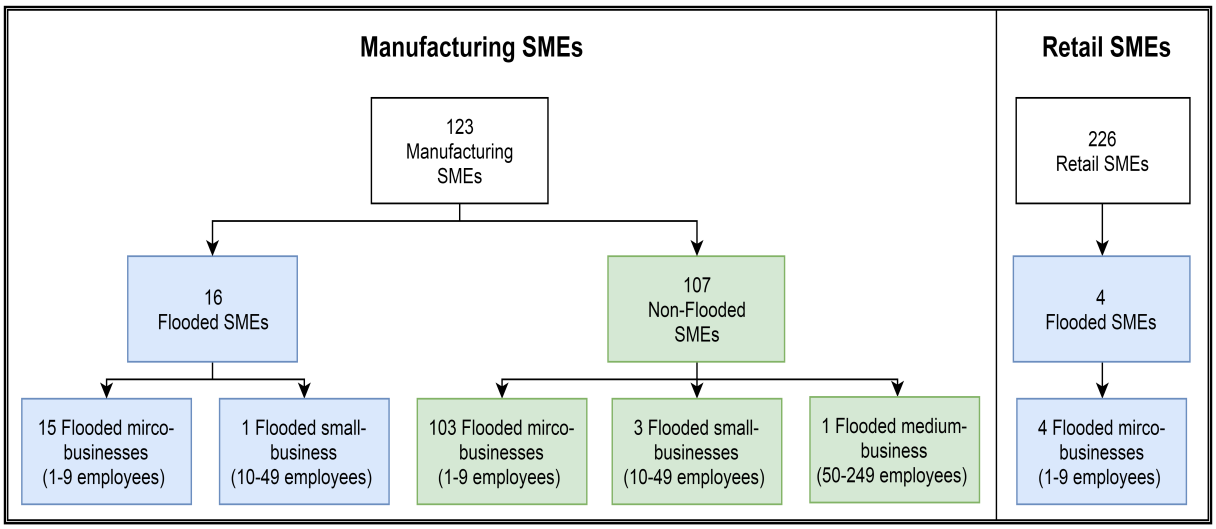


Figure 6. Manufacturing and Retail SMEs Modelled as Agents

Simulation Experiments

Four simulation experiments have been carried out with each representing different collections of precautionary measures implemented by a micro-sized manufacturing and retail SME referred to as 'M' and 'R' in Figure 5. This size of businesses was chosen due to its prevalence within SMEs. In Table 2, these four simulation experiments are defined with a focus on an SME's interaction with related-organisations.

Table 2. Simulation Experiments

Experiment	SME sector	Mutual-aid	Refurbishment by
S1	Manufacturing (M)	Yes	Not applicable
S2		No	Not applicable
S3	Retail (R)	Not applicable	Employees
S4		Not applicable	Refurbishment company

PRELIMINARY RESULTS

For the SMEs located in Tewkesbury, Environment Agency (EA) alerts were received on day 2 at clock time ($t_c = 8{:}00$) and simulation tick ($t_s = 48$), i.e. 36 hours before the flood commenced. Subsequently, EA warnings were received on day 3 ($t_c = 8{:}00$ and $t_s = 104$), that is 3 hours prior to the expected flood commencing. According to SEPA (2019), EA alerts can arrive 36 hours prior to the expected flood commencing whereas warnings may be received approximately 3 hours in advance. After receiving an EA alert ($t_s = 48$), SMEs' employees were allocated to prepare for the potential event and thus the pre-event production level fluctuated between 0% and 100% (see $t_s < 226$ in Figure 7). Specifically, employees were allocated to place sandbags at doorways, cover airbricks, lift-up paper documents, and contact suppliers to pause raw materials/stock dispatch. For the manufacturing SME, employees were additionally prompted to lift-up IT equipment, raw materials, light and medium products, and contact customers to pause product delivery. However, the retail SME's employees were allocated to lift-up sales equipment and lift-up stock.

Manufacturing SME Simulation Experiments

In the two simulation experiments undertaken S1 and S2, for the micro-sized manufacturing SME, the flood commenced at $t_s = 226$ ($t_c = 13{:}00$ on day 6) and receded at $t_s = 742$ ($t_c = 19{:}00$ on day 16), reaching a depth of 0.403m in the premises, as indicated in Figure 7. The flood duration of 516 ticks (i.e. 258 hours), coupled with the depth of water reached, led to 100% of machines and raw materials stored at ground level being damaged. Furthermore, this SME had a total of seven production employees ($E_t^p = 7$) but only six

available ($E_a^p = 6$) in the first day after the flood water receded, then all seven available thereafter.

In Figure 7, two simulation experiments are presented: (i) the red line refers to simulation experiment S1 in which the manufacturing SME has a pre-defined mutual aid partner; (ii) the green line represents simulation experiment S2 in which the manufacturing SME does not have a mutual aid partnership. Note that in the part of Figure 7 labelled (a), for S1 and S2 in the period $t_s = 0$ to 816, the production level is the same thus the red line is hidden by the green line.

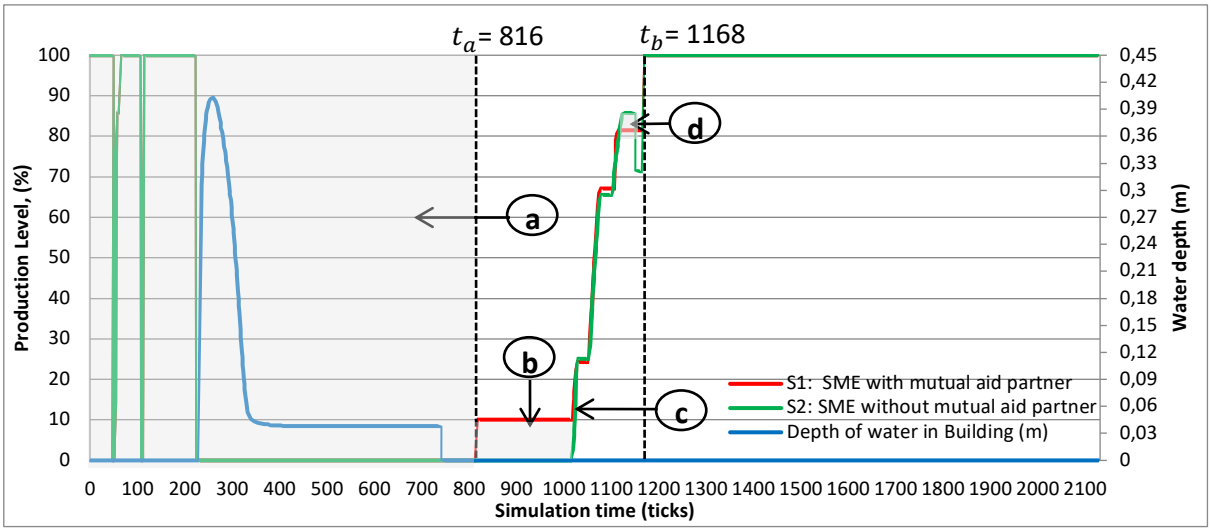


Figure 7. Simulation of Manufacturing SME – Production Level and Flood Water Depth in Premises

In relation to the manufacturing SMEs recovery, given the flood receded outside working hours, ($t_c = 19{:}30$ on day 16), the SME was unable to immediately commence actions that would start the process of recovery. However, at simulation tick $t_s = 768$ ($t_c = 8{:}00$ on day 17), employees in the SME simulated in S1 were allocated to contact their insurance company and their mutual aid partner simultaneously, whereas employees in the SME simulated in S2 were only allocated to do the former.

For S1, during the next day at simulation tick $t_s = 816$ ($t_c = 8{:}00$ on day 18), one production employee (E_p^p=1) was allocated to work on the allocated machines (M_m=10%) at the mutual aid partner's site and thus the production level was restored to PL=10%. Meanwhile, employees of the SME at the flood-affected premises were assigned to drying machines while waiting for compensation to be paid by their insurance company, which would, in turn, enable them to hire electricians and plumbers to carry out repairs (assuming that the SME selected did not have sufficient funds available). At tick $t_s = 962$ ($t_c = 9{:}00$ on day 21), the compensation was paid, enabling employees in the SME simulated in S1 to contact electricians and plumbers, who arrived at tick $t_s = 1011$ ($t_c = 9{:}30$ on day 22). At the same tick, the cleaning service provided by the insurance company arrived and carried out cleaning for 26 hours. Furthermore, at $t_s = 1019$ ($t_c = 13{:}30$ on day 22), with electricity restored, a proportion of production employees were allocated to repair machines, enabling a significant increase in production level (see Figure 7 (c)). At simulation tick $t_s = 1168$ ($t_c = 16{:}00$ on day 25), the employee allocated to work at the mutual aid site returned and started working at the affected SME's site, restoring production level to *PL*=100%.

In relation to simulation experiment S2, compensation was paid at $t_s = 962$ ($t_c = 9{:}00$ on day 21) enabling employees in the SMEs to contact electricians and plumbers who arrived at $t_s = 1011$ ($t_c = 9{:}30$ on day 22) as in S1. At tick $t_s = 1019$ ($t_c = 13{:}30$ on day 22), a proportion of employees were allocated to repair production machines and to work on production, resuming the production level to 2.5%; this was 203 simulation ticks later than the SME simulated in S1 (see Figure 7 (b)). At $t_s = 1121$ ($t_c = 16{:}30$ on day 24), it can be seen that the production level presented in the SME simulated in S2 ($PL \approx 85\%$) is greater than that simulated in S1 ($PL \approx 81\%$). This is due to the percentage of machines repaired in the SME simulated in S2 being greater than those repaired in S1 (see Figure 7 (d)), which had fewer employees in its premises; recall, one employee of the SME simulated in S1 was allocated to work at its mutual aid partner's site. Finally, the production level of the SME simulated in S2 was restored to *PL*=100% at $t_s = 1168$ ($t_c = 16{:}00$ on day 25), exactly the same as in S1.

The average production level loss (PL_{loss}) over a certain time frame ($t_a - t_b$) as shown in Figure 7, is defined in equation (5):

$$PL_{loss} = \frac{\left(100 \times (t_b - t_a)\right) - \left(\sum_{i=t_a}^{i=t_b} h \frac{(f(x_i) + f(x_{i+1}))}{2}\right)}{\left(100 \times (t_b - t_a)\right)} \times 100 \quad (5)$$

where x_i is the simulation tick and $f(x_i)$ is the corresponding production level. This method, which employs the trapezoidal rule (Kreider et al., 2005; Smyth, 2014; Trefethen & Weideman, 2014), subdivides the given interval $[t_a, t_b]$ which refers to the time period post-flood at what the production level is resumed (t_a) and the time at which production level is restored to 100% (t_b). This interval is divided into n sub-intervals of equal width $h = \frac{t_b - t_a}{n}$. In this research, $h = 1$ since $n = t_b - t_a$. Based on the method outlined, the production level associated with each experiment was used to determine the approximate average of production level loss (PL_{loss}). Based on Figure 7, the production level loss of the SME simulated in S1 is $PL_{loss} = 69\%$ whereas the production level of the SME simulated in S2 is $PL_{loss} = 75\%$, i.e. 6% greater than S1.

Retail SME Simulation Experiments

To investigate response and recovery from flooding, the retails SME referred to as 'R' in Figure 5 is simulated with and without a refurbishment company being called to attend its flood-affected premises. As shown in Figure 8, in the two simulation experiments for the micro-sized retail SME, the flood commenced at $t_s = 223$ ($t_c = 23{:}00$ on day 5) and receded at $t_s = 752$ ($t_c = 23{:}30$ on day 16), lasting for 529 ticks (i.e. 264.5 hours) and reaching a depth of 0.901m in the premises. This SME had a total of seven employees ($E_t = 7$) but only six were available ($E_a^p = 6$) in the first day after the flood water receded, then all seven were available thereafter. The recovery profile of service capability is relatively similar for both simulation experiments S3 and S4. Recall, replacing the damaged sales equipment with new equipment prompts the retail SME to restore their sales capability to 100% in a single tick.

For the retail SMEs recovery, a proportion of employees of the SME simulated in S3 and S4 were initially allocated to contact their insurer to (i) enable the flood damage to be assessed, (ii) organise a cleaning service to attend the premises, and (iii) provide financial compensation. After receiving the latter, a proportion of employees were allocated to contact electricians and plumbers to request they attend to carry out the necessary repairs. Furthermore, once electricians and the plumbers arrived at the flood-affected premises, a proportion of employees were allocated to supervise these repairs, along with the cleaning service provider organised by the insurance company. Finally, employees of the SME simulated in S3 and S4 contacted their suppliers to resume delivery of stock, and also to return the lifted-up sales equipment and documents to normal locations. For the SME simulated in S4, employees were additionally allocated to contact a refurbishment company and to supervise them when they arrived.

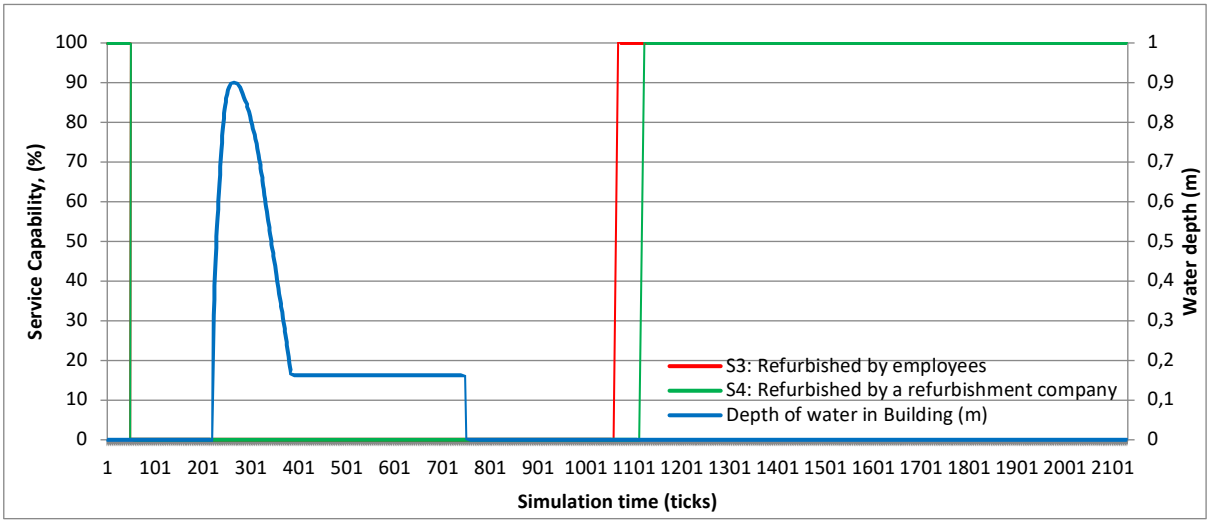


Figure 8. Simulation of Retail SME – Service Capability and Flood Water Depth in Premises

In simulation experiment S3, the service capability was restored to 100% for the retail SME at $t_s = 1065$ ($t_c = 12{:}30$ on day 23), whereas in S4 this was restored to 100% at $t_s = 1119$ ($t_c = 15{:}30$ on day 24), i.e. 54 simulation ticks later than in S3 (see Figure 8). This difference was due to the process undertaken in the retail SME simulated in S4, i.e. contacting a refurbishment company and waiting for them to arrive at the SME's premises (as opposed to allocating their own employees, if able, to carry out refurbishment).

CONCLUSION AND FUTURE WORK

In this paper, an agent based modelling and simulation approach has been presented to assess mutual aid and refurbishment on manufacturing and retails SMEs' recovery from flooding respectively. Within the ABM, a set of pre- and post-flood behaviours have been implemented and examined along with a set of precautionary measures. Two micro-sized SMEs have been selected in the case study presented due to their prevalence in the geographical area in which the flood event was considered, namely Tewkesbury in the UK. This geographical area was selected due to the severe impact of flooding experienced by businesses in 2007.

Four simulation experiments have been defined with each representing a different scenario for the SMEs under consideration. Results show that the manufacturing SME with a pre-defined mutual aid lost 69% of its production over 7 working days whereas the same SME without a mutual aid partnership lost 75% of its production in the same period of time, i.e. a difference of 6%. This significant difference allows a manufacturing SME to maintain production over a period that it would otherwise be non-operational. This provides a motivation for manufacturing SMEs to establish mutual aid partnerships as a way of assisting short-term recovery from a flood event. For retail SMEs, results show that the SME with employees allocated to refurbish its flood-affected premises regained its service capability faster than by employing a refurbishment company, i.e. 27 hours sooner. This difference motivates retail SMEs to allocate employees to refurbish premises, if possible, although it is understandable that not all SMEs' employees are skilled or capable to refurbish. This research will be developed further to involve a larger set of behaviours and precautionary measures and to develop the level of interaction between SMEs and their related-organisations, such as suppliers and customers.

ACKNOWLEDGMENTS

The authors thank colleagues from the School of Civil Engineering at the University of Leeds for providing inundation data from flood event simulation.

REFERENCES

Alharbi, M., & Coates, G. (2017). *An agent-based modelling and simulation framework to assess small businesses' recovery from flooding*. Paper presented at the European Modeling and Simulation Symposium (EMSS), Barcelona, Spain.

Alharbi, M., & Coates, G. (2018). An Investigation of Small and Medium-Sized Enterprises' Flood Preparation and Insurance Coverage using Agent-Based Modelling. *WIT Transactions on the Built Environment, 184*, 143-152.

Ayyagari, M., Demirgüç-Kunt, A., & Beck, T. (2003). *Small and medium enterprises across the globe: a new database*: The World Bank.

British Columbia. (2014). *Mutual Aid Agreement Guideline*. Retrieved from https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/documents/health-and-safety/mem_mutual_aid_guideline_may_2014.pdf

Chatterton, J., Viavattene, C., Morris, J., Penning-Rowsell, E. C., & Tapsell, S. M. (2010). The costs of the summer 2007 floods in England.

Coates, G., Hawe, G., Wright, N., & Ahilan, S. (2014). Agent-based modelling and inundation prediction to enable the identification of businesses affected by flooding. *WIT Transactions on Ecology and the Environment, 184*, 13-22.

Crichton, D. (2008). Role of insurance in reducing flood risk. *The Geneva Papers on Risk and Insurance-Issues and Practice, 33*(1), 117-132.

Dignum, V., & Tick, C. (2007). *Agent-based analysis of organizations: Formalization and simulation.* Paper presented at the Intelligent Agent Technology, 2007. IAT'07. IEEE/WIC/ACM International Conference on.

Gilbert, N., & Terna, P. (2000). How to build and use agent-based models in social science. *Mind & Society, 1*(1), 57-72.

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., . . . Huse, G. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological modelling, 198*(1-2), 115-126.

Hallberg, K. (1999). Small and medium scale enterprises: A framework for intervention. *The World Bank*, 1-22.

Haraguchi, N., Cheng, C. F. C., & Smeets, E. (2017). The importance of manufacturing in economic development: Has this changed? *World Development, 93*, 293-315.

Helbing, D. (2012). Social Self-Organization. Understanding Complex Systems. *Chapter, 2*, 25-70.

Jones, K., & Ingirige, B. (2008). *Extreme weather events and business continuity planning.* Paper presented at the CIB W70 International Conference in Facilities Management.

Kreider, D., Lahr, D., & Diesel, S. (2005). *Principles of Calculus Modeling: An Interactive Approach*: Springer, NY.
Labarthe, O., Espinasse, B., Ferrarini, A., & Montreuil, B. (2007). Toward a methodological framework for agent-based modelling and simulation of supply chains in a mass customization context. *Simulation Modelling Practice and Theory, 15*(2), 113-136.
Li, C., Coates, G., McGuinness, M., & Johnson, N. (2015). Designing an agent-based model of SMEs to assess flood response strategies and resilience.
Lukács, E. (2005). The economic role of SMEs in world economy, especially in Europe. *European integration studies, 4*(1), 3-12.
Macal, C. M., & North, M. J. (2010). Tutorial on agent-based modelling and simulation. *Journal of simulation, 4*(3), 151-162.
North, M. J., & Macal, C. M. (2007). *Managing business complexity: discovering strategic solutions with agent-based modeling and simulation*: Oxford University Press.
Omar, O. E., & Fraser, P. (2010). The role of small and medium enterprise retailing in Britain.
Prasad, M. N., & Chartier, D. A. (1999). *Modeling Organizations Using Agent-Based Simulations*. Paper presented at the Workshop onAgent Simulation: Applications, Models, and Tools.
Rhodes, C. (2015). Business statistics. *Briefing paper, 6152*.
SEPA. (2019). Floodline | Scottish Environment Protection Agency (SEPA). Retrieved from https://www.sepa.org.uk/environment/water/flooding/floodline/
Shim, J., Bliemel, M., & Choi, M. (2017). Modeling complex entrepreneurial processes: A bibliometric method for designing agent-based simulation models. *International Journal of Entrepreneurial Behavior & Research, 23*(6), 1052-1070.
Smyth, G. K. (2014). Numerical integration. *Wiley StatsRef: Statistics Reference Online*.
Stier, D. D., & Goodman, R. A. (2007). Mutual aid agreements: essential legal tools for public health preparedness and response. *American journal of public health, 97*(Supplement_1), S62-S68.
Sullivan-Taylor, B., & Branicki, L. (2011). Creating resilient SMEs: why one size might not fit all. *International Journal of Production Research, 49*(18), 5565-5579.
Sutton, J., & Tierney, K. (2006). Disaster preparedness: Concepts, guidance, and research. *Colorado: University of Colorado*.
Tewkesbury Borough Council. (2018). Tewkesbury floods 2007. Retrieved from https://www.tewkesbury.gov.uk/flooding#statistics
Trefethen, L. N., & Weideman, J. (2014). The exponentially convergent trapezoidal rule. *SIAM Review, 56*(3), 385-458.
United Nations. (2008). *International Standard Industrial Classification of All Economic Activities Revision 4*. New York. https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf
Van Gils, A. (2005). Management and governance in Dutch SMEs. *European Management Journal, 23*(5), 583-589.
Wedawatta, G., Ingirige, B., & Amaratunga, D. (2010). Building up resilienc e of construction sector SMEs and their supply chains to extreme weather events. *International Journal of Strategic Property Management, 14*(4), 362-375.
White, S. (2016). Business population estimates for the UK and regions 2016. *B. a. I. Skills(Ed.). Sheffield*.

Location-allocation model for earthquake shelter solved using MPSO algorithm

Xiujuan Zhao
Tsinghua University
xjzhao@mail.tsinghua.edu.cn

Jianguo Chen
Tsinghua University
chenjianguo@mail.tsinghua.edu.cn

Peng Du
Beijing Global Safety Technology Co., Ltd
dupeng@gsafety.com

Wei Xu
Beijing Normal University
xuwei@bnu.edu.cn

Ran Liu
Beijing Global Safety Technology Co., Ltd
Liuran@gsafety.com

Hongyong Yuan
Tsinghua University
hy-yuan@tsinghua.edu.cn

ABSTRACT

Constructing shelters in suitable quantities, with adequate capacities and at the right locations is essential for evacuees under earthquake disasters. As one of the disaster management methods, constructing shelters can help to significantly reduce disruption and devastation to affected population. Mathematical models have been used to solve this problem allied with a heuristic optimization algorithm. The optimization of evacuation efficiency, as one of the most important objectives, has many expressive forms, such as minimizing evacuation distance and evacuation time. This paper proposes a new model that aims to minimize evacuation time with a new calculation method and to maximize total evacuees' comfort level. The modified particle swarm optimization (MPSO) algorithm is employed to solve the model and the result is compared with a model that calculated evacuation time differently and a model without distance constraint, respectively.

Keywords

Earthquake shelter, location-allocation, evacuation time minimization, comfort level maximization, MPSO.

INTRODUCTION

Natural disasters have caused serious economic losses and casualties (Bilham, 2010; Norio et al., 2011; Yuan, 2008). Many engineering methods have been implemented to protect buildings and infrastructures against damages (Chen and Scawthorn, 2003). However, in some cases, these methods cannot protect people after an earthquake disaster that leaves many people homeless. Therefore, constructing emergency shelters with reasonable locations, sufficient assets and supplies is important to provide safe places to affected people at different phases of a disaster.

In this paper, a new bi-objective model is developed for determining locations of earthquake disaster emergency shelters as well as allocating affected population to specific shelters. Both evacuation time and comfort level of evacuees are considered. The evacuation time is obtained with consideration of evacuation route's width and the number of evacuees of each community. Also, an optimization approach named modified PSO (MPSO) algorithm derived from the work of Zhao et al. (2015) is used to solve the model. The MPSO algorithm incorporates simulated annealing (SA), thus allowing better solutions to be obtained for the earthquake shelter location-allocation problem. Furthermore, Chaoyang District, Beijing, China is selected for the case study and the presented results provide the local government with a solution to the earthquake shelter location-allocation problem.

RELATED WORK

In order to facilitate decision-making, many research have been carried out to help determine shelters' locations and population allocation. The methods used mostly includes spatial analysis of geographical information systems (Gall, 2004; Sanyal & Lu, 2009) and location-allocation mathematical models (Bayram, Tansel and Yaman, 2015; Gama, Scaparra and Santos, 2013; Kilci, Kara, & Bozkaya, 2015; Sherali, Carter, & Hobeika, 1991) that are derived from site selection models. The site selection models includes P-median model (Hakimi, 1964), P-center model (Hakimi, 1965), and covering model (Toregas, Swain, ReVelle, & Bergman, 1970) that have been modified to solve the disaster shelter location-allocation problem. According to the characteristics of the disaster shelter location-allocation problem that the evacuees should be evacuated to assigned shelters as soon as possible, the objective derived from P-median model is most commonly adopted. For example, the work of Sherali et al. (1991), one of the first research applied P-median model in solving disaster shelter location-allocation problem. This work developed a shelter location-allocation model with an objective to minimize the total evacuation time of all affected people to their assigned hurricane shelters. Based on these single-objective models, multi-objective models (Alçada-Almeida, Tralhão, Santos, & Coutinho-Rodrigues, 2009; Barzinpour & Esmaeili, 2014; Doerner, Gutjahr, & Nolz, 2009; Hu, Xu, & Li, 2012; Hu, Yang, & Xu, 2014; Zhao, Xu, Ma, & Hu, 2015) and hierarchical models have been proposed (Z. Chen, Chen, Li, & Chen, 2013; Ng, Park, & Waller, 2010; Widener & Horner, 2011). Multi-objective model is more popular as it can satisfy different requirements simultaneously, such as the objectives to minimise evacuation distance or time, to minimise construction cost and to minimise disaster risks. Among these objectives, the objective of evacuation time minimization is also widely used. Hu et al. (2014) proposed an earthquake shelter location-allocation model with two objectives for solving evacuees' allocation problem, i.e. to minimize total cost and to minimize total distance from communities to their assigned shelters. Similarly, Zhao et al. (2017; 2015), Xu et al. (2017) and Kongsomsaksakul et al. (2005) also developed their models with the objectives to minimize distance or time for evacuees to reach their assigned shelters, respectively. However, the definitions of evacuation time vary in these research. For flood and hurricane disasters, the evacuees are assumed to travel in vehicles and the evacuation time is defined with network model (Bayram et al., 2015; Sherali et al., 1991). Also, some researchers used evacuation distance to represent evacuation time (Alçada-Almeida et al., 2009; Doerner et al., 2009; Rodríguez-Espíndola & Gaytán, 2015). However, evacuees are expected to walk during and after earthquake disasters that cannot be calculated using the method of evacuation time calculation for hurricane and flood disasters. Although Zhao et al.(Zhao et al., 2017, 2015) proposed an earthquake shelter location-allocation model with an objective to minimize evacuation time, it is weighted evacuation time rather than real travel time for all members of a given community to reach their designated shelter. Furthermore, after a severe earthquake disaster, the evacuees may need to stay in shelters for prolonged periods of time. Thus, their comfort should be an important factor. However, the comfort level of evacuees is still not taken into account in current works.

With respect to problem solving methods, geographical information system is employed to solve simple models (Kilci et al., 2015; Ye, Wang, Huang, Xu, & Chen, 2012) while complex models with different objectives and constraints are typically solved using heuristic optimization algorithms such as ant colony optimization (Colorni, Dorigo, & Maniezzo, 1991), genetic algorithms (GAs) (Goldberg, 1989), particle swarm optimization (PSO) (Kennedy & Eberhart, 1995) and simulated annealing (Kirkpatrick, Gelatt, & Vecchi, 1983). Compared with other heuristic optimization algorithms, PSO algorithm exhibits properties including straightforward calculation process, simple parameters, and fast convergence. Also, it has been modified with simulated annealing (SA) to avoid premature convergence (Hu et al., 2012; Zhao et al., 2015).

MATHEMATICAL MODEL, OPTIMIZATION METHODS AND CASE STUDY

In this section, a mathematical model for the earthquake shelter location-allocation problem is developed. Also, MPSO, the optimization heuristic algorithm employed to solve the location-allocation model is described. Furthermore, an overview of the case study designed to demonstrate the results of the model solved with the MPSO algorithm is presented.

This work makes four assumptions as described below:

1) All residents of a community will be allocated to the same shelter;

2) The residents queue to evacuate and each evacuee occupies 1 square meter;

3) Residents will go to their assigned shelters along the shortest route from their locations;

4) The residents of a given community will be assigned to only one shelter.

Shelter location-allocation model

The objective to minimize the total evacuation time is used widely to ensure the affected people can arrive to their shelters as soon as possible. Also, the comfort level is important as the evacuees would live in their shelters for a long time after a severe earthquake disaster. Non-utilized area of a shelter for each evacuees is one of the import factors to affect their comfort level. Thus in the preliminary study reported in this paper, a model with two objectives to minimize the total evacuation time and to maximize total comfort level are proposed with a distance constraint and a capacity constraint. In this paper, the comfort level is simplified to non-utilized area before a community coming.

The notation used in this paper is shown as below.

i: Index of objective, equal to 1, 2, …,I

j: Index of community equal to 1, 2, …, M

k: Index of candidate shelter, equal to 1, 2, …, N

t_{kj}: Travel time from community j to shelter k

B_{kj}: Whether or not community j is assigned to shelter k, equal to 1 or 0

L_{kj}: Non-utilized capacity of shelter k before community j coming

d_{kj}: Shortest evacuation route's distance from community j to shelter k

D_j: The maximum evacuation distance that community j can travel

P_j: The number of people within community j

C_k: Capacity of candidate shelter k

X_k: Whether or not candidate shelter k is selected, equal to 1 or 0

w_p: Path width of an evacuation occupies

W_{kj}: The weighted mean width of the evacuation paths that form the entire route taken by community j to candidate shelter k i

v_j: Evacuation speed of the people in community j

a_i: Weight of objective i

$$\min f_1 = \sum_{j=1}^{M}\sum_{k=1}^{N}\left(t_{kj} \times B_{kj}\right) \tag{1}$$

$$\min f_2 = \sum_{j=1}^{M}\sum_{k=1}^{N}\left(L_{kj} \times B_{kj}\right) \tag{2}$$

$$d_{kj} \times B_{kj} - D_j \le 0 \qquad \forall k = 1,2,...,N; \forall j = 1,2,...,M \tag{3}$$

$$\sum_{j=1}^{M}\left(P_j \times B_{kj} - C_k \times X_k\right) \le 0 \qquad \forall k = 1,2,...,N \tag{4}$$

$$\sum_{k=1}^{N}\left(B_{kj} \times X_k\right) = 1 \qquad \forall j = 1,2,...,M \tag{5}$$

Equation (1) is the objective to minimize total evacuation time of all communities where t_{kj} is the minimum evacuation time from community j to candidate shelter k that can be obtained using Equation (6).

$$t_{kj} = \frac{d_{kj} + \dfrac{P_j}{w_P \times W_{kj}}}{v_j} \tag{6}$$

In Equation (6), the evacuation time of a community is the time required for all residents of the community to reach their shelter. Here, the distance for the final evacuee of a community is adjusted by the number of evacuees of this community, the occupied width of an evacuee and the width of the evacuation route as shown in Figure 1.

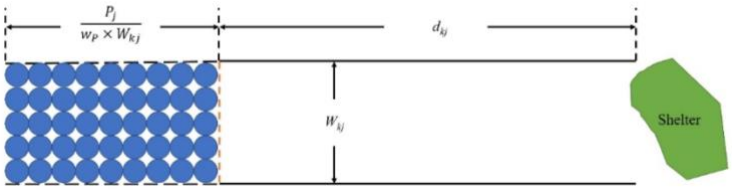


Figure 1 Evacuation distance adjustment

Parameter d_{kj} in Equation (6) is the shortest distance obtained using Dijkstra algorithm, P_j is the number of evacuees in community j, w_p indicates the width that an evacuee needs which in this paper is assumed to be 1 meter. W_{kj} is the average width of the shortest route from community j to shelter k and v_j is the average evacuation speed of community j calculated as:

$$v_j = (2 \times p_c \times v_c + (p_a - p_c) \times v_a + p_o \times v_o) \times \rho \tag{7}$$

where v_c, v_a and v_o represent the speed of a community's children, adults and elderly people that is defined by Gates et al. (2006), and p_c, p_a, and p_o are the proportions of these three categories of people respectively. The parameter ρ is an adjustment parameter of the evacuation speed relative to the ordinary speed that is set as 1 in this paper.

In Equation (1), B_{kj} is a decision variable that indicates if the community j will be allocated to shelter k (1 allocated, 0 otherwise). Equation (2) is the objective to maximize the comfort level of all evacuees in their allocated shelters. The parameter L_{kj} indicates the non-utilized capacity of shelter k before community j coming. Equation (3) represents the distance constraint that a candidate shelter cannot be selected by a given community if the distance is greater than D_j, the farthest this community can reach. Equation (4) indicates the capacity constraint that the number of evacuees allocated to a shelter cannot exceed the capacity of the shelter. Here, C_k is the capacity of shelter k that can be obtained by total area of shelter k divided by smallest refuge area per person, i.e., 1 m^2 (Beijing Municipal Institute of City Planning & Design, 2007). X_k is a decision variable that indicates whether the candidate shelter k will be selected (1 selected, 0 otherwise). Equation (5) ensures that a community can only be allocated to one shelter.

Modified particle swarm optimization algorithm

The model proposed in this paper involves different two objectives. There are different approaches can be taken to solve models involving multiple objectives such as Pareto-based approach and converting the multi-objective problem to a single objective problem. This conversion can be achieved by summing the weighted values of each of the multiple objectives to be an average assessment index as shown in Equation (8). I is the number of objectives and a_i is the weighted value of objective function f_i. The weight assigned to each objective function can be determined according to the prior information on the relative importance of each one. Here, it should be noted that the units should keep consistent.

$$\min f = \sum_{i=1}^{I} (a_i \times f_i) \tag{8}$$

In the preliminary work reported in this paper, the weighted-based approach is used and the two objectives can be converted to a single one, to minimize average assessment index, as shown in Equation (9). In the preliminary work presented in this paper, both the two weights, a_1 and a_2 are set as 0.5. To eliminate the effect of the units, a normalization approach is employed as shown in Equation (9). $f_{1,\min}$ and $f_{2,\min}$ are the minimum values of function 1 and 2 respectively that are solved individually neglecting the other function. Similarly, $f_{1,\max}$ and $f_{2,\max}$ are the maximum values of function 1 and 2 respectively that are solved individually neglecting the other function.

$$\min f = \left(a_1 \times \frac{f_1 - f_{1,\min}}{f_{1,\max} - f_{1,\max}} \right) + \left(a_2 \times \frac{f_{2,\max} - f_2}{f_{2,\max} - f_{2,\min}} \right) \tag{9}$$

To solve the model proposed in this paper, MPSO algorithm is introduced by adding SA to PSO algorithm. The pseudo code for the MPSO algorithm is presented in Algorithm 1. MPSO algorithm begins with a population of size 100 that is generated randomly via the INITIALIZE function. The particle of swarm P is named u. After the first 100 iterations, the solution of each subsequent iteration will be compared with previous 100 solutions. If there is no difference between them, then a new particle swarm is generated using INITIALIZE function. The MPSO process executes until the convergence is met, i.e., the solution remains the same for 1,000 iterations.

Algorithm 1 MPSO

```
1:  P ← INITIALIZE(popSize)
2:  While (MPSO not converged) do
3:    COMPUTEOV(P)
4:      for each particle in P
5:       if von Neumann topology then
6:         v ← UPDATE_v(p, v, p_best, n_best)        ▷ Update particle's velocity
7:      else
8:         v ← UPDATE_v(p, v, p_best, g_best)        ▷ Update particle's velocity
9:      p ← UPDATE_p(p, v)                           ▷ Update particle's position
10:     if p_current > p_best
11:       p_best ← p_current
12:     else
13:       p_best ← apply SA(p_current)               ▷ Apply SA
14:     if von Neumann topology then
15:       for each particle in P
16:         n_best ← UPDATE_n(p_n, n_best)           ▷ Update best of neighbours
17:     else
18:         g_best ← UPDATE_g(p_g, g_best)           ▷ Update global best
19:     if PREMATURE(P) then
20:       P ← INITIALIZE(popSize)
```

In algorithm 1, both von Neumann topology and global topology are used. More specifically, if using the von Neumann topology, each particle's velocity and position in iteration t+1, v_u^{t+1} and p_u^{t+1}, are updated using Equations (10) and (13) respectively. If using the global topology, each particle's velocity and position in iteration t+1, v_u^{t+1} and p_u^{t+1}, are updated using Equations (11) and (13) respectively.

$$v_u^{t+1} = \varphi(v_u^t + c_1 r_1 (p_{best,u}^t - p_u^t) + c_2 r_2 (g_{best}^t - p_u^t)) \quad (10)$$

$$v_u^{t+1} = \varphi(v_u^t + c_1 r_1 (p_{best,u}^t - p_u^t) + c_2 r_2 (g_{best}^t - p_u^t)) \quad (11)$$

$$\varphi = \frac{2}{|2 - (c_1 + c_2) - \sqrt{(c_1 + c_2)^2 - 4(c_1 + c_2)}|} \quad (12)$$

$$p_u^{t+1} = p_u^t + v_u^{t+1} \quad (13)$$

where φ is the constriction coefficient introduced by Clerc and Kennedy (2002) to guarantee convergence by avoiding the explosion of the particle swarm. It is a function of c_1 and c_2 as shown in Equation (10) that are the cognitive and social acceleration coefficients respectively where $c1$=2.8 and $c2$=1.3 leading to a value of φ=0.7298. In Equation (8) and (9), r_1 and r_2 are generated randomly in the range [0, 1]. For each particle, the fitness value of each particle can be calculated using COMPUTEOV function that is Equation (1). For each particle, its best position so far, $p_{best,}$ can be replaced by its current position, $p_{current}$, if $p_{current}$ is better. However, if $p_{current}$ is worse than $p_{best,}$ SA is applied such that a worse position can be accepted with a lower probability. When von Neumann topology is used, the best position among neighbouring particles, n_{best} is updated via the UPDATE_n function that compares the positions of neighbours of a particle, p_n. When using global topology, the best position among all particles, g_{best} is updated by comparing it with all other particles.

Case study

Figure 2 illustrates the location of the geographical area for case study in this paper, namely Chaoyang District,

Beijing, China. More specifically, Figure 2(a) shows the location of Beijing in China and Figure 2(b) shows the location of Chaoyang in Beijing.

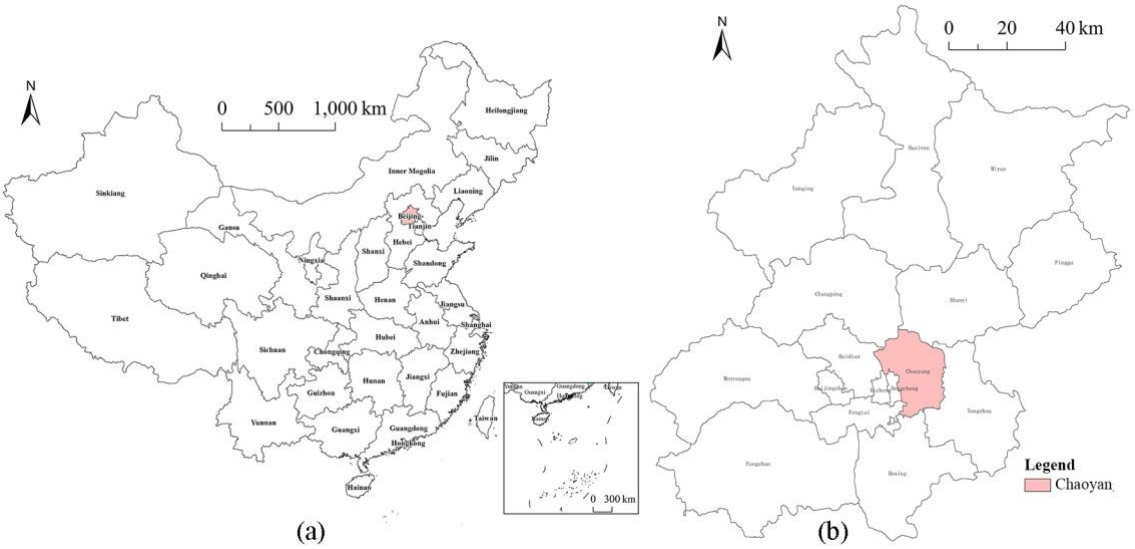


Figure 2. Location of Jinzhan, Chaoyang, Beijing, China

Figure 3(a) presents a map of communities, shelters and evacuation path network, which was provided by the Key Laboratory of Environmental Change and Natural Disaster of Ministry of Education, Beijing Normal University. Figure 3(a) indicates the locations of 72 candidate shelters and 463 communities that need to be allocated to the designated shelters. All these 72 candidate shelters are more than 500m from the earthquake faults, have slopes less than 20°, and covered by basic facilities in consideration of the safety requirement (Hu et al., 2014). The area of these 72 candidate shelters are shown in Table 1. The 463 communities in Chaoyang District are shown in Figure 3(b) that is provided by the Beijing Bureau of Civil Affairs. It shows that the population of Chaoyang is mainly concentrated in the central part of the district while the northwest and southeast look to be the most sparsely populated areas.

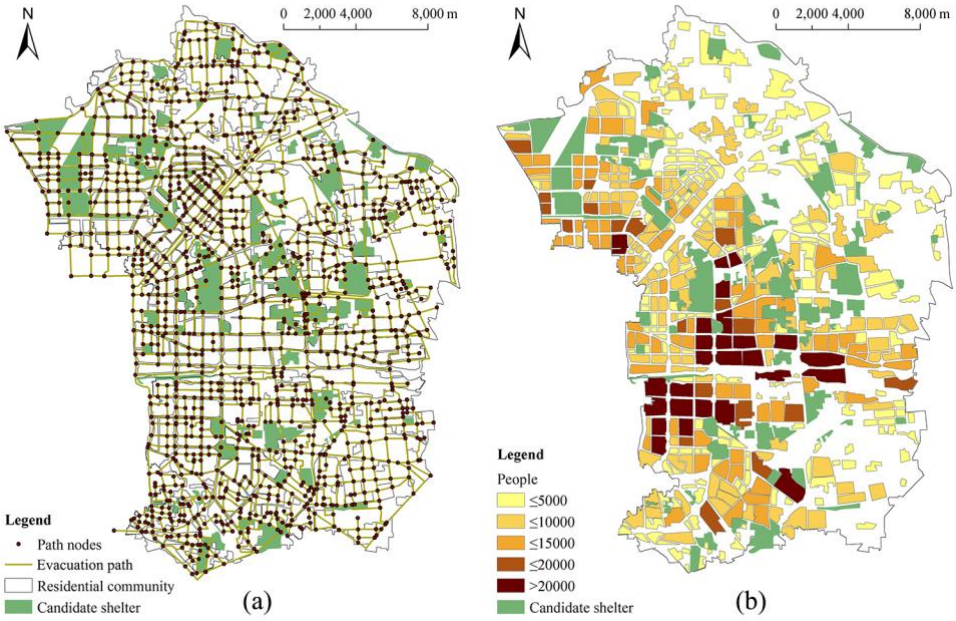


Figure 3. Location of communities, shelters, evacuation paths and distribution of population

Table 1. Area of candidate shelters

Index	Area (m^2)	Index of	Area (m^2)	Index	Area (m^2)	Index	Area (m^2)
1	4159154	19	913338	37	132689	55	760155
2	129008	20	1131302	38	557720	56	205123
3	1287289	21	1198171	39	1389666	57	225276
4	148632	22	151359	40	683912	58	101332
5	1054839	23	628007	41	1134819	59	185707
6	137168	24	435675	42	116883	60	154885
7	1747887	25	451206	43	182029	61	3259571
8	410019	26	1947589	44	209357	62	4025508
9	1965047	27	666949	45	151982	63	416397
10	444471	28	710093	46	1303315	64	632137
11	221256	29	458265	47	534468	65	1671783
12	1781155	30	211451	48	239690	66	104041
13	2351361	31	1281952	49	314890	67	170633
14	813119	32	336887	50	505944	68	1344011
15	708023	33	841863	51	512862	69	1852361
16	84579	34	966195	52	190563	70	232708
17	336393	35	562851	53	422104	71	244959
18	604975	36	547908	54	260175	72	217352

PRELIMINARY RESULTS AND DISCUSSION

As the location-allocation problem involves a large number of communities and candidate shelters, and different constraints, the aforementioned MPSO algorithm was adopted. The program executes 9 times in a laptop with 16GB memory and 2.2 Hz Intel Core i7. It needs average 5 minutes to obtain the result for each execution. In this section, the shelter selection and community allocation to the selected shelters are shown at first. Also, the average assessment index of each community is analyzed. Then, the result is compared with the result of the model with objective to minimize total evacuation time and the model without the distance constraint.

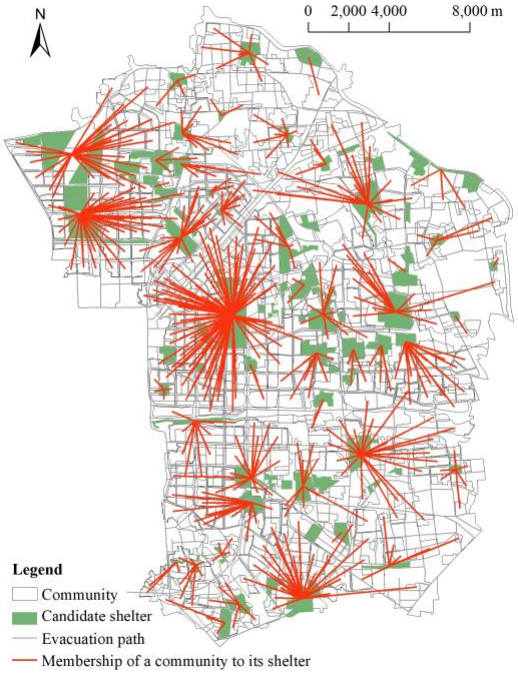


Figure 4. Location-allocation result

Figure 4 presents the result of shelter selection and how the 463 communities are allocated to them. A total of 47 shelters are being selected. The value of f , f_1, and f_2 are 0.2116, 5.47×10^5 and 2.83×10^8 respectively. It can be seen that shelters with larger capacity exhibit higher attractiveness that many relatively distant communities are allocated to them. In comparison, smaller shelters mainly serve communities more closely located.

Figure 5(a1) and (b1) shows the value of evacuation time of each community and non-utilized capacity before

each community coming respectively. Also, the value ranges of them are shown in Figure 5(a2) and (b2) respectively. It illustrates that the value of evacuation time, for each community is less than 4,500 seconds, among which, even some of them are less than 500 seconds. The evacuation time for community 161 is the most that is 4,274 seconds while that for community 64 is the least. Most of the value for non-utilized capacity before a community coming is less than 4.2×10^6 m^2 and more than 4.3×10^4 m^2. Also, it can be seen that the value of evacuation time is more concentrated than the value of non-utilized capacity before communities coming.

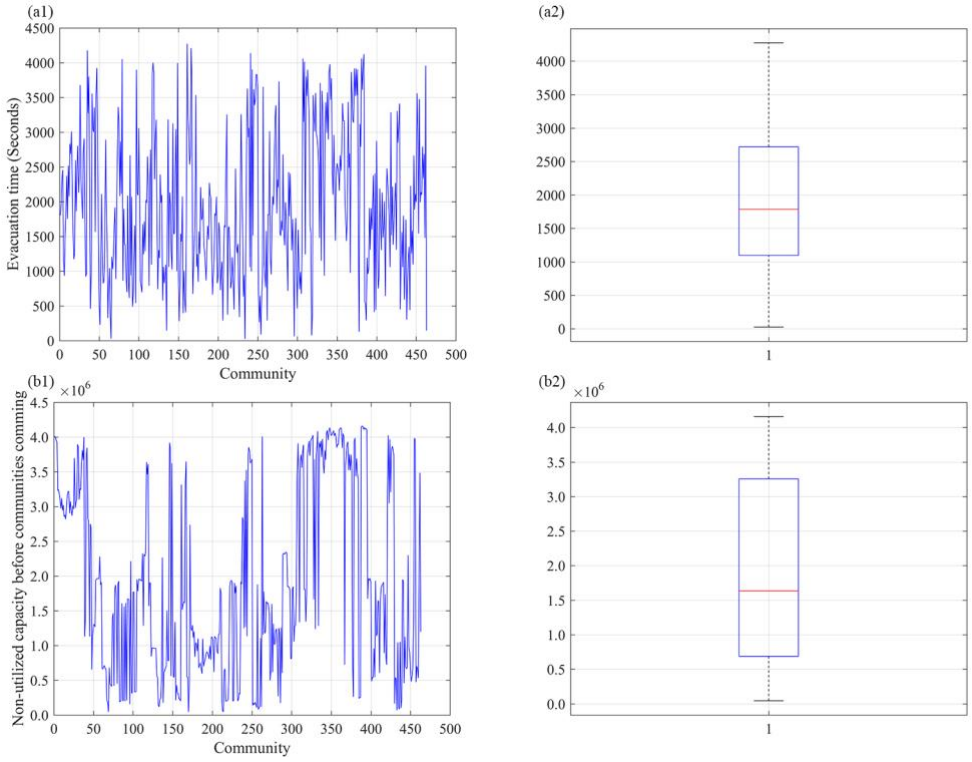


Figure 5 Evacuation time of each community and non-utilized shelter capacity before each community coming

The proportion of utilized and non-utilized area of 47 selected shelters are visualized in Figure 6. It presents that the utilized area is obviously less than the non-utilized area for all selected shelters. For shelter 43, the proportion of utilized area is the largest amongst all of 47 shelters with the value of 0.269. Thus, as the proportion of non-utilized area for all selected shelters is more than 0.5, each selected shelter has sufficient room to house relief workers and volunteers. Also, there is enough room for relief assets storage and movement of evacuees.

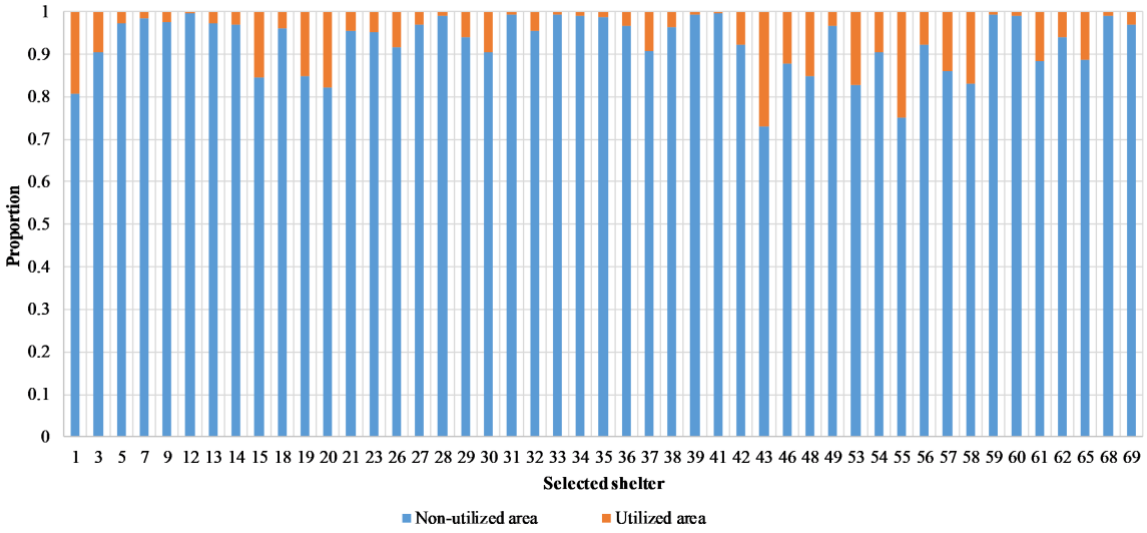


Figure 6 Proportion of utilized area and non-utilized area of each selected shelter

The result aforementioned is derived from solving the model with distance constraint described in subsection 'Shelter location-allocation model'. However, if the evacuees are not sensitive to long distance, the result will be different. Also, if the evacuees only pay attention to evacuation time neglecting the comfor level, the objective will be the mere minimization of total evacuation time. To compare with the model proposed in this paper, a model without distance constraint and a model with the objective to minimize total weighted evacuation time as shown in Equation (14) are also solved using MPSO algorithm.

$$\min f_3 = \sum_{j=1}^{M}\sum_{k=1}^{N} \frac{d_{kj}}{v_j} \times \frac{P_j}{W_{kj}} \times B_{kj} \qquad \forall k = 1, 2, \ldots\ldots, N \quad \forall j = 1, 2, \ldots\ldots, M \tag{14}$$

The location of the candidate shelters selected and how the 463 communities are allocated to them obtained using the aforementioned two models are shown in Figure 7(a) and Figure 7(b) respectively. In Figure 7(a), it can be seen that there are 46 shelters being selected. It is less than 47 shelters obtained using the model with distance constraint as shown in Figure 4. However, some communities would be allocated to shelters that the distances are too long. Figure 7(b) presents locations of 65 selected shelters and the allocation of communities to them. It indicates that the number of shelters needed is more than that of the models with the two objectives proposed in this paper and the values of both f_1 and f_2 for this solution is more than those of the solution obtained by the bi-objective model.

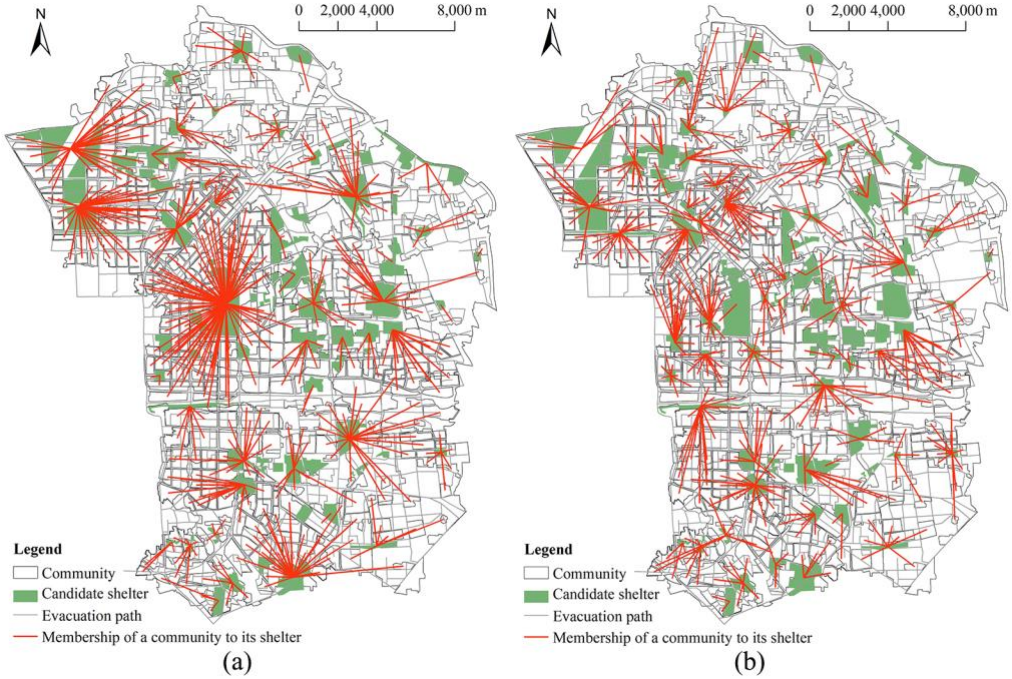


Figure 7 Location-allocation results of the model without distance constraint and the model to minimize total evacuation time

CONCLUSION

The aim of this paper is to present preliminary work in solving the proposed earthquake disaster shelter location-allocation problem. Findings in this work will facilitate future efforts for developing a more realistic mathematical model.

In this paper, a mathematical model with two objectives is proposed with capacity and distance constraints. The result obtained using this model is compared with a model without distance constraint and a model with objective to minimize total evacuation time, respectively. It is observed that the model proposed in this paper enables the balance between evacuation time and comfort level. In terms of further work, a number of improvements will be made to the mathematical model. For example, comfort level will be calculated dynamically rather than statically as in this paper. Also, other objectives can be considered in terms of the specifications of earthquake shelters such

as construction cost and damage risk. Also, the changing situations of volume of evacuees and damages to road networks caused by an earthquake will be considered. Moreover, improvement of the heuristic optimization algorithm will be carried out for more rapid and accurate problem solving.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support provided by National Natural Science Foundation of China and Macau Science and Technology Development Joint Fund (NSFC-FDCT) (No. 71861167002).

REFERENCES

Alçada-Almeida, L., Tralhão, L., Santos, L., & Coutinho-Rodrigues, J. (2009). A multiobjective approach to locate emergency shelters and identify evacuation routes in urban areas. *Geographical Analysis*, *41*(1), 9–29. https://doi.org/10.1111/j.1538-4632.2009.00745.x

Barzinpour, F., & Esmaeili, V. (2014). A multi-objective relief chain location distribution model for urban disaster management. *International Journal of Advanced Manufacturing Technology*, *70*(5–8), 1291–1302. https://doi.org/10.1007/s00170-013-5379-x

Bayram, V., Tansel, B. T., & Yaman, H. (2015). Compromising system and user interests in shelter location and evacuation planning. *Transportation Research Part B: Methodological*, *72*, 146–163. https://doi.org/10.1016/j.trb.2014.11.010

Beijing Municipal Institute of City Planning & Design. (2007). Planning of earthquake and emergency shelters in Beijing central districts (outdoors). Retrieved from http://xch.bjghw.gov.cn/web/static/articles/catalog_84/article_7491/7491.html

Bilham, R. (2010). Lessons from the Haiti earthquake. *Nature*, *463*(7283), 878–879. https://doi.org/10.1038/463878a

Chen, W.-F., & Scawthorn, C. (2003). *Earthquake Engineering Handbook* (Vol. 332). https://doi.org/10.1126/science.332.6028.412

Chen, Z., Chen, X., Li, Q., & Chen, J. (2013). The temporal hierarchy of shelters: A hierarchical location model for earthquake-shelter planning. *International Journal of Geographical Information Science*, *27*(8), 1612–1630. https://doi.org/10.1080/13658816.2013.763944

Clerc, M., & Kennedy, J. (2002). The particle swarm - explosion, stability, and convergence in a\nmultidimensional complex space. *IEEE Transactions on Evolutionary Computation*, *6*(1), 58–73. https://doi.org/10.1109/4235.985692

Colorni, A., Dorigo, M., & Maniezzo, V. (1991). Distributed Optimization by Ant Colonies. In *Proceedings of the first European Conference on Artificial Life* (Vol. 142, pp. 134–142). https://doi.org/10.1016/S0303-2647(97)01708-5

Doerner, K. F., Gutjahr, W. J., & Nolz, P. C. (2009). Multi-criteria location planning for public facilities in tsunami-prone coastal areas. *OR Spectrum*, *31*(3), 651–678. https://doi.org/10.1007/s00291-008-0126-7

Gall, M. (2004). Where to Go? Strategic Modelling of Access to Emergency Shelters in Mozambique. *Disasters*, *28*(1), 82–97. https://doi.org/10.1111/j.0361-3666.2004.00244.x

Gama, M., Scaparra, M. P., & Santos, B. (2013). Optimal location of shelters for mitigating urban floods. In *EURO Working Group on Transportation* (Vol. 00).

Gates, B. T. J., Noyce, D. A., Bill, A. R., Van Ee, N., & Gates, T. J. (2006). Recommended Walking Speeds for Pedestrian Clearance Timing Based on Pedestrian Characteristics. *Transportation Research Record: Journal of the Transportation Research Board*, (Volume 1982 / 2006), 38–47. https://doi.org/10.3141/1982-07

Goldberg, D. (n.d.). AG-1-David E. Goldberg Genetic Algorithms in Search, Optimization, and Machine Learning.pdf.

Hakimi, S. L. (1964). Optimum locations of switching centers and the absolute centers and medians of a graph. *Operations Research*, *12*(3), 450–459. https://doi.org/10.1287/opre.12.3.450

Hakimi, S. L. (1965). Optimum Distribution of Switching Centers in a Communication Network and Some Related Graph Theoretic Problems. *Operations Research*. https://doi.org/10.1287/opre.13.3.462

Hu, F., Xu, W., & Li, X. (2012). A modified particle swarm optimization algorithm for optimal allocation of earthquake emergency shelters. *International Journal of Geographical Information Science*, *26*(9), 1643–1666. https://doi.org/10.1080/13658816.2011.643802

Hu, F., Yang, S., & Xu, W. (2014). A non-dominated sorting genetic algorithm for the location and districting planning of earthquake shelters. *International Journal of Geographical Information Science*, *28*(7), 1482–1501. https://doi.org/10.1080/13658816.2014.894638

Kennedy, J., & Eberhart, R. (1995). Particle Swarm Optimization. In *Proc. of IEEE International Conference on Neural Networks* (Vol. 5, pp. 1942–1948).

Kilci, F., Kara, B. Y., & Bozkaya, B. (2015). Locating temporary shelter areas after an earthquake: A case for Turkey. *European Journal of Operational Research*, *243*(1), 323–332. https://doi.org/10.1016/j.ejor.2014.11.035

Kirkpatrick, S., Gelatt, C. D., & Vecchi, M. P. (1983). Optimization by Simulated Annealing. *Science*, *220*(4598), 671–680. https://doi.org/10.1126/science.220.4598.671

Kongsomsaksakul, S., Yang, C., & Chen, A. (2005). Shelter location-allocation model for flood evacuation planning. *Journal of the Eastern Asia Society for Transportation Studies*, *6*(1981), 4237–4252. https://doi.org/10.11175/easts.6.4237

Ng, M. W., Park, J., & Waller, S. T. (2010). A Hybrid Bilevel Model for the Optimal Shelter Assignment in Emergency Evacuations. *Computer-Aided Civil and Infrastructure Engineering*, *25*(8), 547–556. https://doi.org/10.1111/j.1467-8667.2010.00669.x

Norio, O., Ye, T., Kajitani, Y., Shi, P., & Tatano, H. (2011). The 2011 eastern Japan great earthquake disaster: Overview and comments. *International Journal of Disaster Risk Science*, *2*(1), 34–42. https://doi.org/10.1007/s13753-011-0004-9

Rodríguez-Espíndola, O., & Gaytán, J. (2015). Scenario-based preparedness plan for floods. *Natural Hazards*, *76*(2), 1241–1262. https://doi.org/10.1007/s11069-014-1544-2

Sanyal, J., & Lu, X. X. (2009). Ideal location for flood shelter: A geographic information system approach. *Journal of Flood Risk Management*, *2*(4), 262–271. https://doi.org/10.1111/j.1753-318X.2009.01043.x

Sherali, H. D., Carter, T. B., & Hobeika, A. G. (1991). A location-allocation model and algorithm for evacuation planning under hurricane/flood conditions. *Transportation Research Part B*, *25*(6), 439–452. https://doi.org/10.1016/0191-2615(91)90037-J

Toregas, C., Swain, R., ReVelle, C., & Bergman, L. (1970). The Location of Emergency Service Facilities. *Operations Research*, *19*(6), 1363–1373. https://doi.org/10.1287/opre.19.6.1363

Widener, M. J., & Horner, M. W. (2011). A hierarchical approach to modeling hurricane disaster relief goods distribution. *Journal of Transport Geography*, *19*(4), 821–828. https://doi.org/10.1016/j.jtrangeo.2010.10.006

Xu, W., Ma, Y., Zhao, X., Li, Y., Qin, L., & Du, J. (2017). A comparison of scenario-based hybrid bilevel and multi-objective location-allocation models for earthquake emergency shelters: a case study in the central area of Beijing, China. *International Journal of Geographical Science*. https://doi.org/10.1080/13658816.2017.1395882.

Ye, M., Wang, J., Huang, J., Xu, S., & Chen, Z. (2012). Methodology and its application for community-scale evacuation planning against earthquake disaster. *Natural Hazards*, *61*(3), 881–892. https://doi.org/10.1007/s11069-011-9803-y

Yuan, Y. (2008). Impact of intensity and loss assessment following the great Wenchuan Earthquake. *Earthquake Engineering and Engineering Vibration*, *7*(3), 247–254. https://doi.org/10.1007/s11803-008-0893-9

Zhao, X., Coates, G., & Xu, W. (2017). Solving the earthquake disaster shelter location-allocation problem using optimization heuristics.

Zhao, X., Xu, W., Ma, Y., & Hu, F. (2015). Scenario-based multi-objective optimum allocation model for earthquake emergency shelters using a modified particle swarm optimization algorithm: A case study in Chaoyang District, Beijing, China. *PLoS ONE*, *10*(12), 1–16. https://doi.org/10.1371/journal.pone.0144455

Improving Emergency Response through Business Process, Case Management, and Decision Models

Marco Polo Ruiz Herrera
Universitat Politècnica de València
marruih1@posgrado.upv.es

Juan Sánchez Díaz
Universitat Politècnica de València
jsanchez@dsic.upv.es

ABSTRACT

The emergency procedures contain a set of actions responsible for providing the necessary corrective measures to address an emergency. The relevance of contextual knowledge during emergency responses is of utmost importance since many decisions are made from the information gathered in real time that sometimes conflicts with the formal knowledge specified in the emergency plan. Consequently, tools that support the emergency plan mentioned must be sensitive to context and allow decision making at the time an emergency takes place. We demonstrate how Case Management Modeling Notation (CMMN) along with Decision Model and Notation (DMN) are very suitable approaches to obtain a flexible model adapted to the context-driven response processes.

Keywords

Emergency response, Knowledge-intensive business, Business Process Model and Notation, Case Management Model and Notation, Decision Model and Notation.

1.- INTRODUCTION

Emergency plans are a set of actions and measures aimed at preventing and controlling risks to people and their property in order to respond appropriately to the possible emergency situations to which an organization is exposed. Response procedures within self-protection plans, are actions told in natural language that are carried out immediately in light of the event of a disaster with the aim of preventing the loss of life, safeguarding goods and normalizing the situation as soon as possible (Sánchez et al., 2015); however, due to its nature and the variants that may occur, the self-protection plan must be executable, scalable, adaptable and, flexible.

The problems of nature classified as knowledge-intensive business models should be addressed with notation based on Adaptive Case Management (ACM) (Di Ciccio et al., 2014; Hofmann et al., 2015). Due to the increase in natural disasters that have occurred in the last decade, one of the fields of application with greater interest at present is emergency management. However, at the time of modeling solely with traditional process notations (e.g., Business Process Model and Notation (BPMN)) it is difficult to define beforehand possible scenarios (Van der Aalst et al., 2005). In addition, critical factors such as time, excessive information from the environment, poor structuring the unrepeatable and unpredictable flow must be considered (Jul, 2007; Kushnareva et al., 2015).

In May 2014, the Object Management Group (OMG) formalized the case management language (Case Management Model and Notation (CMMN)) in its version 1.0 (OMG, 2014), which allows to graphically represent flexible response procedures based on cases to respond to the emergencies. Even though in December 2016, OMG presented version 1.1 of CMMN (OMG, 2016) where it attended the technical details of the original version, some case workers consider it still immature and doubt that it is appropriate to apply it for critical domains in real-world such as the emergency management (Kurz, 2015). Although CMMN allows the ACM, not all response procedures keep the same classification during all stages. Therefore, there are tasks that can be automated to facilitate decision-making with DMN and give continuity to the flow of response with BPMN. This paper aims to integrate the BPMN, CMMN, and DMN specifications to build what we call the **ACM hybrid model**, which allows us to adequately represent the different characteristics of emergency response procedures and when executed, adequately manage the needs of the environment.

This paper is organized as follows: section 2 describes the related works that use modeling notations to provide attention to emergencies. Section 3 explains how the BPMN, CMMN, and DMN specifications can be integrated to represent a response process named the ACM hybrid model. Section 4, as a case study, analyzes the proposal to build an ACM hybrid model based on the fire response management procedure of the Hospital Universitario y Politécnico de La Fe in the city of Valencia, Spain. Section 5 shows the execution of the ACM hybrid model using the Camunda BPM environment. Finally, section 6 presents the key findings and possible future work.

2.- RELATED WORK

In the literature, there are several studies that consider the methodology of process modeling a viable alternative to represent the emergency response processes and provide adequate responsiveness. Hofmann et al. conducted a broad structured review of the literature to identify the different existing approaches that apply methods and tools of business process management (BPM) to the domain of Disaster Response Management (DRM), concluding that it is a promising approach because of the similarity between the general structure and the aims of both business processes and disaster response processes. In addition, as a result of the research work, they obtained an adequate classification of the requirements necessary for the development of business process solutions oriented to DRM (Hofmann et al., 2015).

In 2005, Van der Aalst et al. proposed an approach in which case management was used to support flexible business processes. They identified and classified the main entities of the system and built a meta-model as part of their conclusions and found that case management offered a balance between support and flexibility, however, this paradigm alone did not solve all the problems related to changes (Van der Aalst et al., 2005).

Zensen and Küster conducted a comparison between the BPMN language with an ad-hoc subprocess approach and the CMMN notation to represent the same case study. They aimed to identify advantages and disadvantages of each language and help choose which standard to use to model processes or part of processes that require flexible parts. They concluded that the BPMN ad hoc subprocess offered a certain degree of flexibility but that arbitrary jumps were difficult to model. Likewise, they recommend that in knowledge-intensive business problems, the data should be restricted to individual tasks that should not be shared with all participants of the process. CMMN offered a greater degree of work flexibility where tasks could be grouped in stages that had semantic similarity in execution and support a declarative approach. The disadvantage was the lack of outgoing communication events. In their conclusions, they suggested a combination of both to model highly structured and flexible processes (Zensen and Küster, 2018).

Nešković and Kirchner discussed in their work the main benefits of CMMN over BPMN when modeling knowledge-intensive business problems that require using context information to allow flexibility in runtime. The technical proposal was illustrated with an example in health domain. They concluded that CMMN was designed to model only a high level of business logic, while other details remain to be specified and developed at the level of specific applications. Therefore, they recommend developing an extension for CMMN that provides this support (Nešković and Kirchner, 2016).

Recently, Shahrah and Al-Mashari have shown how CMMN can be used to model an emergency response process. They used CMMN to build a template model for a generic emergency response process and indicated that the generic model can be easily expanded or exchanged between different modeling tools or existing execution platforms. Also, they presented a case study of a flood management process as an example of the use of CMMN in the modeling of the emergency response process. Finally, they concluded that the CMMN has great potential to model case-based processes such as emergency response (Shahrah and Al-Mashari, 2017).

As can be seen from the literature review described above, and as far as we know, we did not find a case study using hybrid ACM modeling, integrating the notations of BPMN, CMMN, and DMN to represent emergency response processes. Therefore, this paper attempts to help explain the implementation of a hybrid ACM model in the emergency response domain.

3.- AN INTRODUCTION TO CMMN AND DMN

Case management (CM) was introduced as a new paradigm for business process support systems (Van der Aalst et al., 2005) focusing on the data-centered process, knowledge-intensive, flexible and adaptable processes. As opposed to traditional business process management (BPM), based on control flow, where the order of execution of activities is determined by the execution of previous activities, CM allows the execution of weakly structured process, where the dynamic selection of activities to accomplish a business goal is based upon case worker skills and the evolution of case data. CM supports the ad-hoc, dynamic and unpredictable interactions between people, process fragments, data and, documents.

Emergency response procedures are typical examples of case management: interactions between different roles or independent agencies such as fire department, police, public transportation, etc. Also fragments of unstructured response activities ready to change their behavior at runtime.

The language CMMN (Case Management Modeling Notation) is a new standard for case management published by the OMG in 2014 (OMG, 2014). The case is the main concept, which lists all possible case roles and references the Case File Model and the Case Plan Model. The Case File holds all the data used in the case; the members of the Case File are Case File Items which can be any type of information ranging from a plain file (typically encoded in XML) to a folder hierarchy. Figure 1 shows the graphic representation of CMMN elements.

The Plan Model contains the behavioral aspects of the Case Model: events, tasks, stages, and milestones, called Plan Items. The events can be activated either manually by users (user event listener), by the system after an elapsed period of time (timer event listener) or by changes detected in the Case File model (anonymous event listener). Note that the Case File implicitly includes the context for throwing events to the Case Plan Model. A human task is a unit of work performed by a user of the Case. There are two types of human tasks: blocking task (tracked by the system) and non-blocking task (manual task). Additionally, there are two more task types: process task and case task. A process task calls an external process passing parameters as required. In the same way, a case task calls an external case, providing the necessary information when necessary.

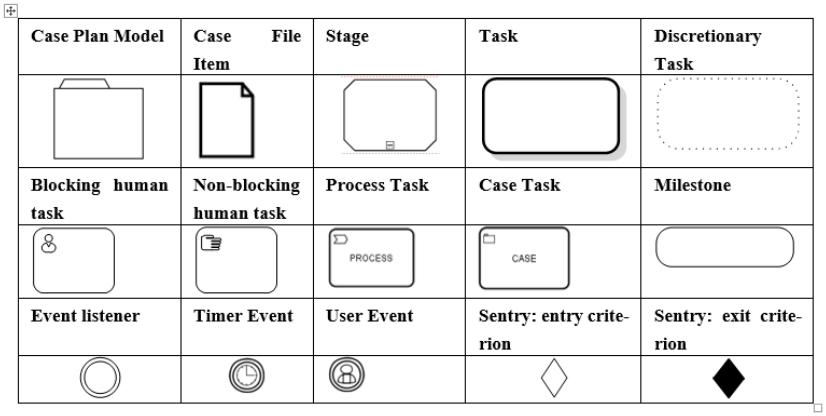


Figure 1. Elements of CMMN

A milestone represents a state reached during the case execution, which enables evaluation of case progress. The dependencies between elements of the case are modeled using event-condition pairs called Sentry, which can be of two types: entry criterion and exit criterion. The Sentry with entry criterion can be attached to case items as stages, tasks, and milestones. When the event of the Sentry occurs, and the conditions are evaluated as true the corresponding attached elements are enabled. Similarly, an exit criterion can be attached to tasks and stages. Upon task or stage completion the exit criterion terminates the attached plan item. A stage contains Plan Items and Sentry elements, to achieve one (or more) of the milestones owned by that stage.

Within the context of CMMN, a case has two distinct phases: design and execution. During the design phase, business analysts are engaged in modeling the case, which includes defining stages or tasks. During the execution phase, the case workers create and execute the plan, particularly by performing tasks as planned, while the plan may continuously evolve, due to the same or other case workers being engaged in planning and execution, i.e., adding so-called 'discretionary plan-items' (tasks and stages) to the plan of the case instance at run-time. This fundamental characteristic of case management, supported by CMMN, is referred to as 'runtime flexibility'. It allows process participants to respond to challenges or new requirements that were not considered at the time of planning the business processes. This run-time planning is based on information that has become available to the case. Changing the case behavior means changing a case process.

Decision Modeling and Notation (DMN) is a new standard from OMG. The DMN notation has been designed to work alongside BPMN, providing a mechanism for modeling the decision-making represented in a task within a process model. DMN does not need to be used with BPMN but it is highly compatible. The DMN standard allows to model and describe decisions in a declarative way on two levels, the requirements level, and the decision logic level. The first level employs Decision Requirements Diagrams (DRD). These diagrams can contain several types of elements, decisions, input data, business knowledge models, and knowledge sources. A DRD diagram shows where the information required for the evaluation of decisions comes from. The second level uses a declarative language called Friendly Enough Expression Language (FEEL) to describe the decision logic or decision tables.

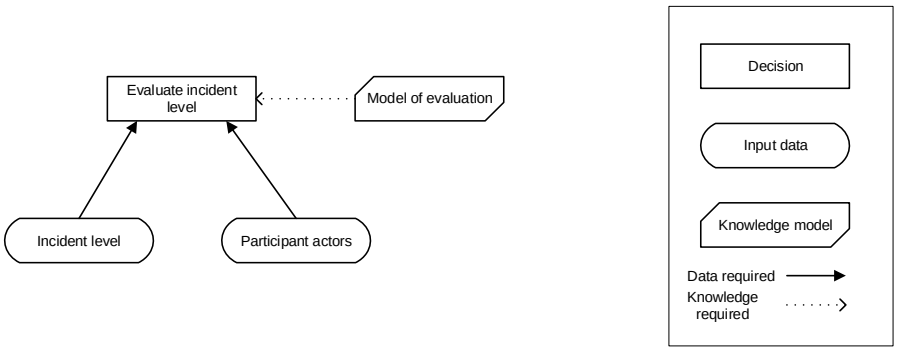


Figure 2. DRD diagram.

Figure 2 shows a decision requirement diagram with a top decision, two inputs data, and a knowledge model. The decision logic is implemented in Figure 5 using a decision table.

4.- CASE STUDY

In this section, we describe a case study of a specific emergency response process example. This case study aims to demonstrate how hybrid ACM modeling can be used appropriately to represent real situations in emergency management. The example of the case study to be used is the emergency response procedure of thin case of fire developed for the Hospital Universitario y Politécnico de La Fe located in the city of Valencia, Spain. This process was extracted from the self-protection plan that the institution provided us with and aims to define the sequence of actions to be developed for the initial control of a possible fire-type emergency, planning of the human performance, and the means available to the hospital. In essence, the hospital aims to avoid the partial or total evacuation of the center. If an evacuation in the hospital is needed, it will define the necessary guidelines so that it is carried out in the orderly, organized and easy way possible.

It is advisable that before reading the response procedures of the self-protection plan, the actors involved are identified. Likewise, they should be aware of its abbreviations, missions, functions to play and the activities to be carried out in each of the phases of the emergency. To facilitate the understanding of the emergency response procedure of the case study, Figure 3 shows the Action Diagram, which summarizes the possible sequences of action by each of the actors in the response procedure of the fire-type incident.

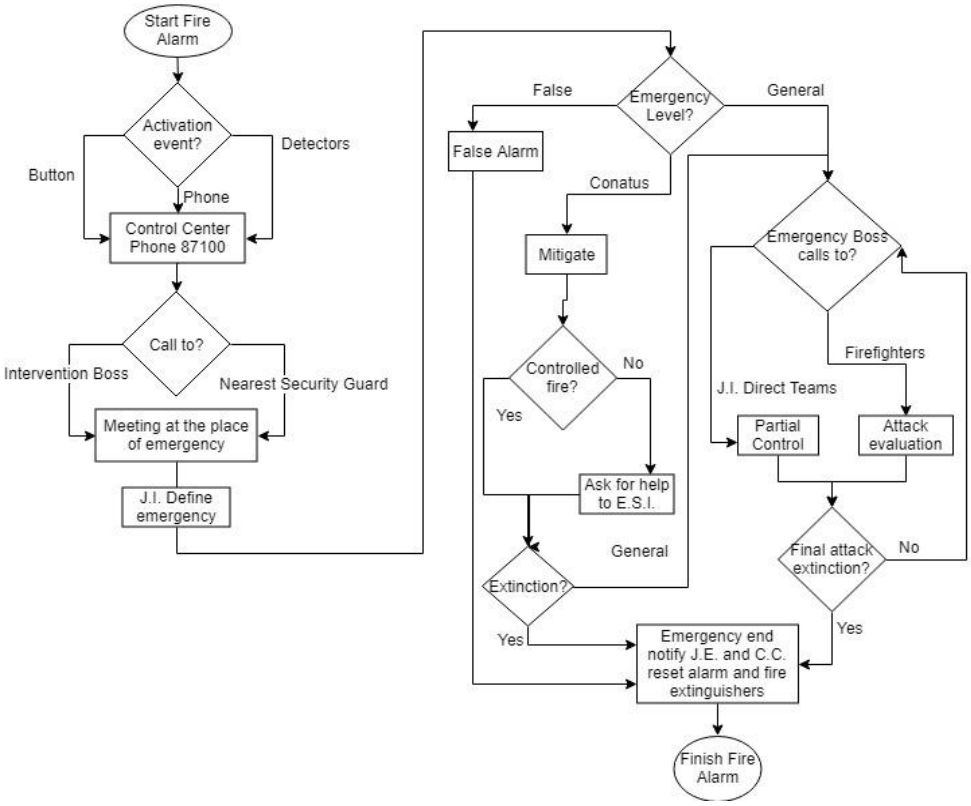


Figure 3. Action diagram of the fire-type incident response procedure.

The previous Action Diagram, facilitates the understanding of the emergency response procedure, However, there are activities that lack a clear sequence and the moment in which they must be performed, thus, this representation of the response procedure creates ambiguities and therefore, the sequence in the control flow is very unreliable when trying to make the response procedure executable in real time.

Once known and understood the content of the emergency response procedure, it is advisable to identify the key business elements and the relationship between them to facilitate the design of the hybrid ACM model.

Following the recommendations provided by the OMG standard to integrate the BPMN, DMN, and CMMN specifications as well as the content of the emergency response procedure of the case study, it is defined that the diagram in BPMN will be chosen as a base in order to potentiate the automation of the sequence. Therefore, the lanes of the pool will be the **Control Center**, **Security Guard,** and the **Emergency Boss**. With the help of the Camunda Modeler tool (Camunda Modeler, 2018), models and decision tables will be designed. It is important to note that in addition to the diagram, the digital object of each model contains in XML format the description of it, allowing the core of the BPM Camunda platform to interpret and execute the models (Camunda Engine, 2018).

Next, in Figure 4 is presented the model M0. Fire Management in BPMN, as a result of the fire-type emergency response process that was summarized in the Action Diagram of the Figure 3.

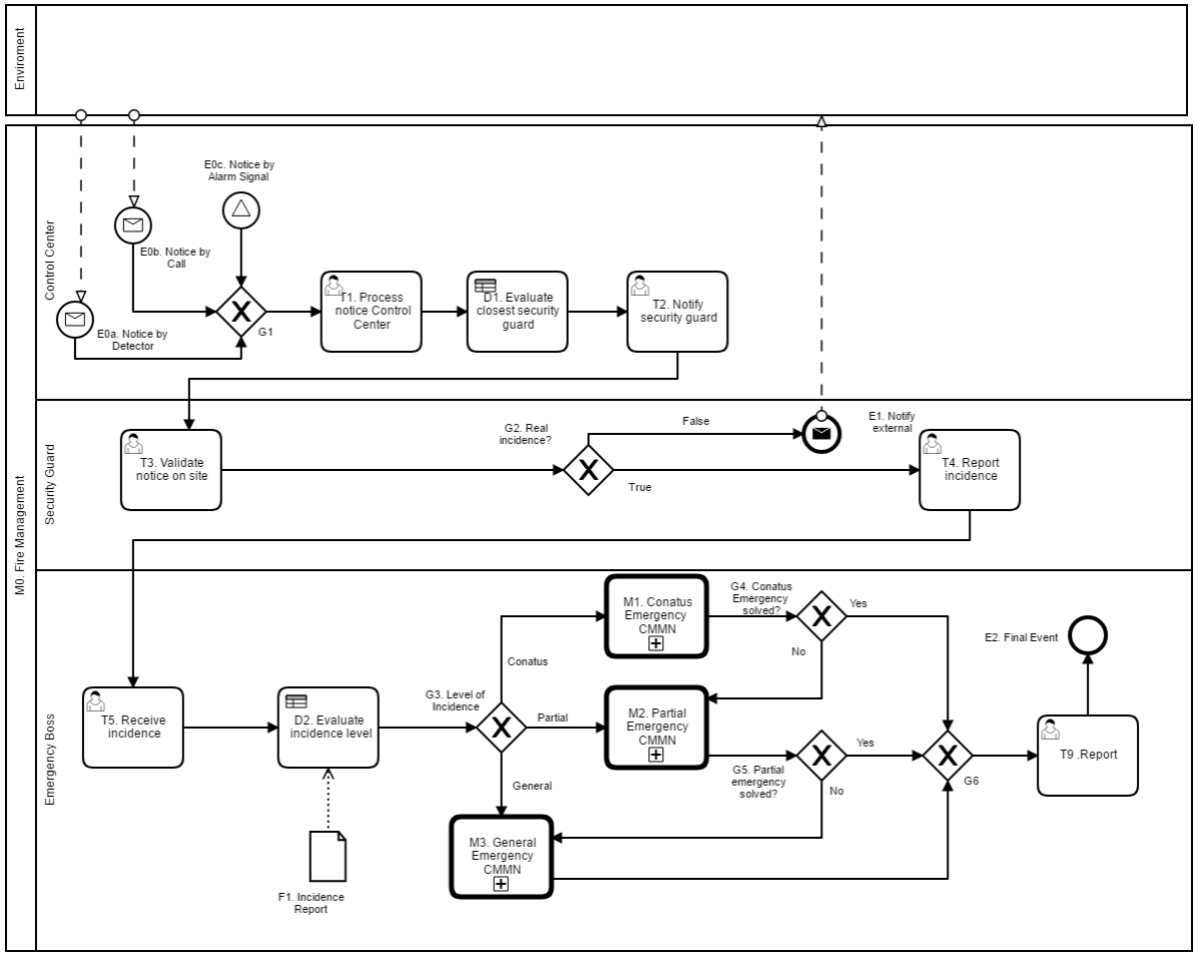


Figure 4. Model M0. Fire Management in BPMN of the Fire-type Incident

To start building the model in BPMN, it is identified in Figure 3 that the fire alarm can be activated by a telephone call, alarm signal or smoke detector, therefore, it is established that the initial events that can create an emergency instance will come from the Environment and are represented by circles. This is an example of how, based on the Action Diagram of Figure 3, the BPMN model of Figure 4 was built. Subsequently, the exclusive gateway G1 will be activated, and the information detailing the initial message will be notified in user task **T1. Process notice Control Center** and using the decision table task in DMN named **D1. Evaluate the closest security guard**, the security guard assigned to go to the incident area will be assigned to validate the emergency.

If the incidence is not real, the Environment is notified through the final event **E1. Notify externaly**; if the incidence is real, the security guard complements the **F1. Incidence Report** through task **T4. Report incidence**, this information allows the emergency boss to determine, through decision table **D2. Evaluate incidence level** in DMN, the incidence level and activate one of the ad-hoc sub-processes **M1. Conatus Emergency**, **M2. Partial Emergency,** or **M3. General Emergency** (ISGF, 2017); which are a call to the models that are in CMMN notation. Based on the output information of each of the ad-hoc sub-processes, the exclusive gateways G4, G5, and G6 bifurcate the workflow to activate another ad-hoc sub-process or reach the **T9. Report** task that when is completed, ends instance using the **E2. Final Event**.

Figure 5 shows the decision table **D2. Evaluate incidence level** in DMN to facilitate the emergency boss to evaluate which actors are going to intervene and the level of the incidence.

Model of Evaluation

DecisionIncidenceLevel

U	Input +		Output +
	Incident Level incidenceLevel	Actors Intervention actors	incidence
	string	string	string
1	"Simple"	"Local Staff"	Conatus
2	"Simple"	"Second Intervention"	Partial
3	"Simple","Limited"	"Local Staff","Second Intervention"	Partial
4	"Potential"	"Personal Local","Segunda Intervención","Pùblic Service"	General
+	-	-	-

Figure 5. Decision table: D2. Evaluate incidence level.

The Case Plan Model **M1. Conatus** in notation CMMN is illustrated in Figure 6, where the stage **M1S1. Mitigate Conatus Emergency** contains the user task **M1T1. Notify the intervention Chief** of manual activation, the task **M1T2. Mitigate Conatus Emergency** indicates to the hospital security personnel mitigate the fire with local resources. Last, through the task **M1T3. Evaluate the emergency** the user validates if the fire has been extinguished. The exit of the stage connects with the gateway **G4. Conatus Emergency Solved?** of general model **M0. Fire Management** in BPMN.

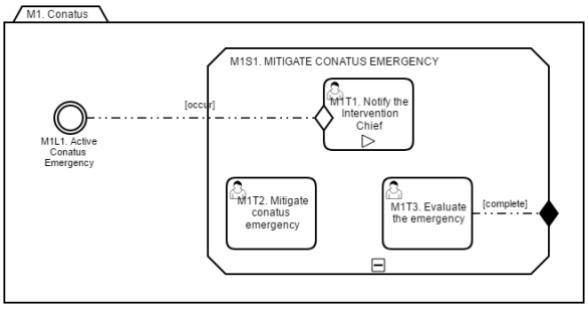


Figure 6. M1. Conatus Emergency Model in CMMN

In Figure 7, we represent the CMMN model **M2. Partial Emergency** where the stage **M2S1. Mitigate Partial Emergency** contains tasks such as **M2T1. Notify the Intervention Chief**, **M2T2. Active partial alarm signal**, **M2T3. Notify second intervention teams**, **M2T4. Evacuate visits from the area**, **M2T5. Evacuate area**, **M2T6. Mitigate fire,** and **M2T7. Evaluate partial situation**; likewise, a milestone **M2H1. Partial Emergency**. The exit in this stage connects with the gateway **G5. Partial Emergency Solved?** of general model **M0. Fire Management**.

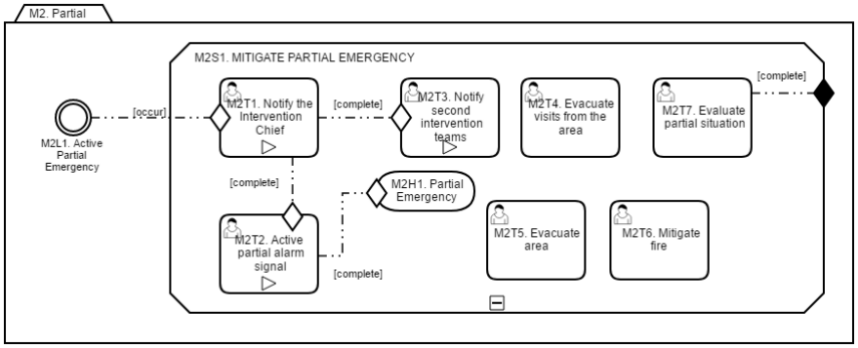


Figure 7. M2. Partial Emergency Model in CMMN

Finally, the model **M3. General Emergency** in CMMN notation (shown in Figure 8) includes the stage **M3S1. Pre-Evacuation** in which we have the tasks **M3T1. Notify firefighters**, **M3T2. Pre-evacuation procedure**, **M3T4. Receive external information** and the decision table **M3D1. Evaluate evacuation**. Furthermore, we have included the stage **M3S2. Evacuation** that connects the tasks **M3T5 Evacuation procedure**, **M3T6. Receive external information** and **M3T7. Evaluate general situation**. The exit of the model is linked with gateway **G6** of general model **M0. Fire Management**.

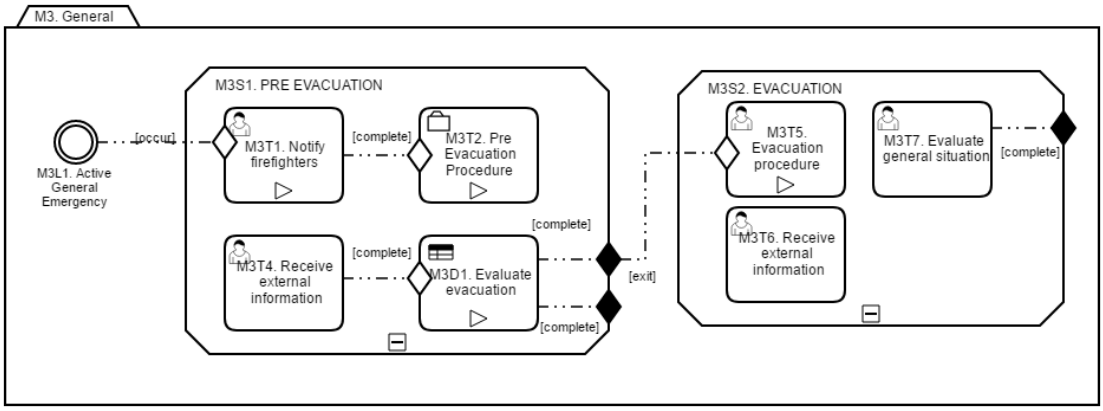


Figure 8. M3. General Emergency Model in CMMN

5.- EXECUTION ENVIRONMENT

Once we built the ACM hybrid model in the Camunda Modeler tool, we should use the BPM Camunda platform, which must be installed and configured together with the Eclipse Maven environment (Camunda Services, 2016). These settings allow one to execute the models and be able to perform simulations of various environments validating the behavior of the models with respect to variants and unrepeatable situations typical of emergency management. One of the benefits of Camunda BPM is the interoperability with other environments through web requests based on the Hypertext Transfer Protocol (HTTP), so it can be consumed through the Application Programming Interface service of the Representational State Transfer type known as the API REST. With the help of the Postman tool, we send a POST request method to simulate the activation of the fire alarm signal with the data shown in Figure 9 and with this create an execution instance.

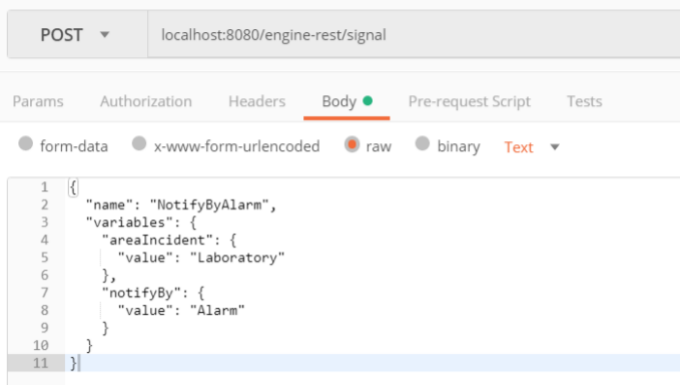


Figure 9. Activation of fire alarm signal via Postman

After this, we run the BPM Camunda platform and enter the TaskList application, finding in the option "My Task" the list of tasks of model **M0. Fire Management**. When we choose task **T1. Process notice Control Center**, we observe the data received from Postman.

On this occasion, to simplify the presentation of the paper, the fire at the **Conatus Emergency** level has been chosen as a sample, in order to validate one of the possible scenarios that may occur during the fire-type emergency in the hospital. In Figure 10, we represent the scenario of the conatus emergency using the orange color to indicate the instantiated items and in red the order of the workflow sequence in the model **M0. Fire Management**. In step 7 of the workflow, when the **T4. Report Incidence** task is activated, the security guard can complement the information for the **F1. Incidence Report** that is loaded in the **D2. Evaluate Incidence Level** and provides to the Emergency Boss, the decision making of the actors that will participate in the mitigation of the incident and establishes the level of the incident.

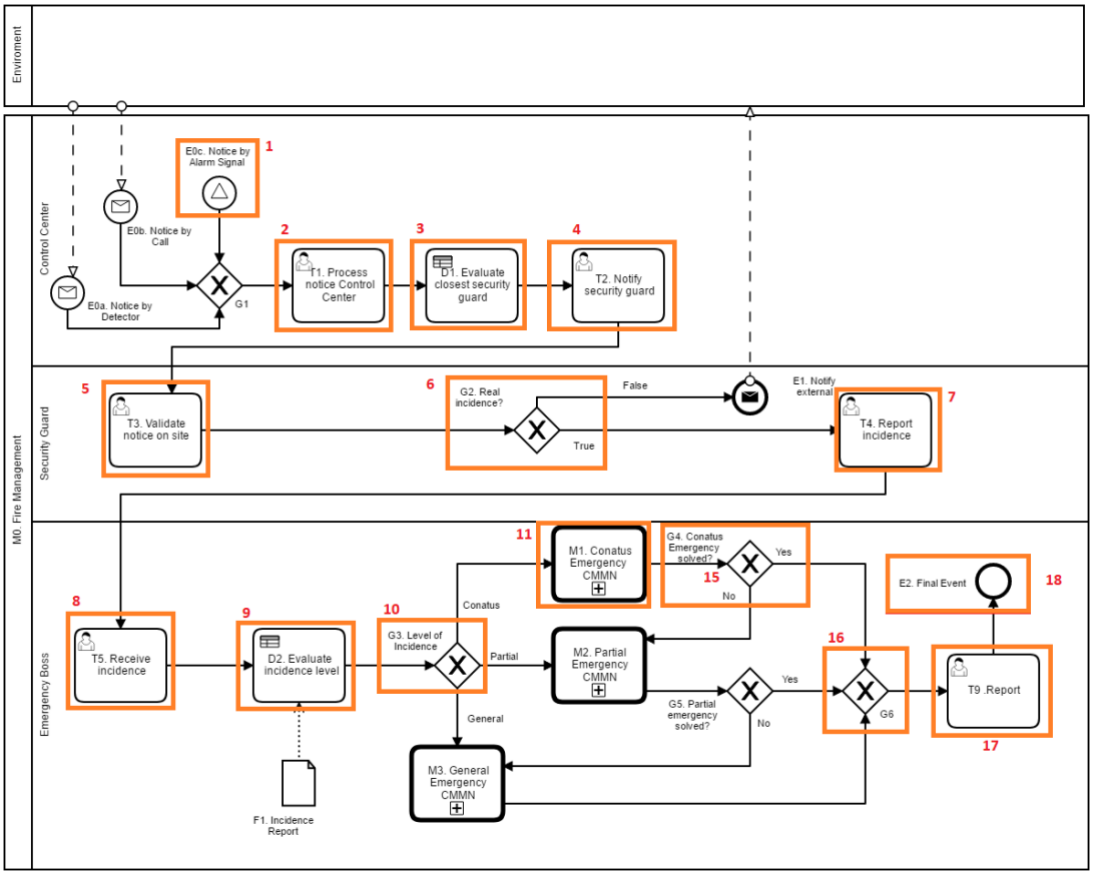


Figure 10. Representation of conatus emergency in model M0. Fire Management.

When the workflow in the simulation reaches **M1. Conatus Emergency**, a call is made to the model in CMMN notation, in Figure 11 we represent the continuation of the execution flow where the case worker intervenes to choose the tasks that will be activated.

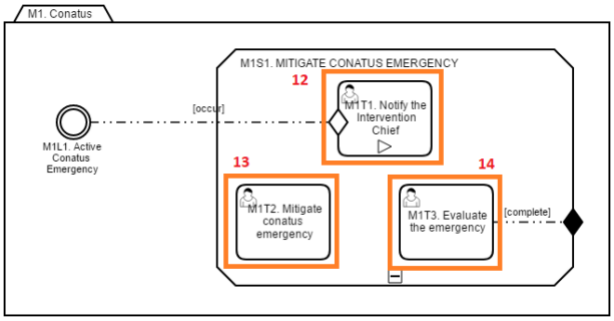


Figure 11. Representation of conatus emergency in model M1. Conatus Emergency.

With the help of the BPM Camunda platform and entering the variables of the environment via Postman for the activation of the instance, the emergency response procedure of fire type represented with the proposed ACM hybrid model has been implemented in a promising way for different scenarios.

However, we found that the web interface of the TaskList application of the BPM Camunda platform is not adequate for the interaction of the case worker during the emergency management. This was mainly because the tasks are presented as a list, which could lead to confusion when choosing the right element to instantiate. Although the Camunda BPM platform is a tool capable of executing models in BPMN, CMMN, and DMN, and its core can be consumed by API REST, the interface for a case worker is not adequate in emergency situations. Therefore, it is necessary to build a tool that maximizes the execution core's potential allowing to strengthen interoperability with other external systems and designing an appropriate interface to the case worker for emergency management. Likewise, the hybrid ACM model by integrating the BPMN, CMMN and DMN specifications would allow to create a library of processes, case definitions and business rules that facilitate the validation of new case studies.

6.- CONCLUSION AND FUTURE WORK

Emergency response procedures are characterized by being dynamic, highly knowledgeable and unstructured; therefore, they are classified as knowledge-intensive processes. Dealing with unrepeatable and unpredictable flows implies that the model must be flexible and adaptable. The Adapted Case Management appears as one of the most attractive and viable innovations in this context, thus, it has been decided to apply to the domain of emergency management. However, in most of the proposals, it is offered to choose between the modeling approach oriented to traditional processes such as BPMN or in case management as CMMN. With BPMN we find that its main benefit lies in the autonomy and agility of the execution because the pre-established conditions are the ones that guide the tasks that should be carried out in the workflow. With CMMN we obtain more flexibility, it relapses the direction of the flow in the events and the decisions taken by the case worker, the latter based on the experience of the case worker. As we can see, the greater the autonomy, the less flexibility.

Although CMMN allows attending for the adaptive case management, in emergency response procedures it is not possible to generalize that at all times the intervention of the case worker is required and to depend entirely on their experience for decision making. There are stages in which the execution can be accelerated by relying on traditional modeling approaches such as BPMN and DMN. By integrating the different approaches, we can obtain a flexible and agile model.

This document briefly presented the characteristics of the different process modeling approaches, including BPMN, DMN, and CMMN; it was demonstrated with the case study based on the of fire type incident of the Hospital Universitario y Politécnico de La Fe in the city of Valencia, Spain, how a hybrid ACM model can be built, where the BPMN, DMN and CMMN standards are integrated to represent artifacts and how they will interact with each other when a dynamic, unrepeatable and unpredictable scenario occurs. Likewise, it was shown, how the different standards converge.

ACM hybrid modeling is a promising proposal to provide support for emergency response processes and there are some modeling tools and execution platforms. Although this is the case, modeling and execution tools are still required to facilitate integration and interaction of different languages, to be adapted to an interface that provides the adequate support for emergency management.

Our future work will focus on implementing the proposal of the hybrid ACM modeling in other emergency response procedures to contrast with other cases of study. We will also focus on the development of a tool that facilitates the implementation of the proposed ACM hybrid models in an appropriate environment to the emergency management and the interoperability with external systems.

ACKNOWLEDGMENTS

The work of Marco Ruiz Herrera has been financed with the scholarship "CONACYT- GOBIERNO DEL ESTADO DE CHIAPAS" whose resources are contributed by the “Consejo Nacional de Ciencia y Tecnología” (CONACYT) of the Government of Mexico and the “Consejo de Ciencia y Tecnología del Estado de Chiapas” (COCYTECH). The work of Juan Sánchez Díaz is funded by the Spanish MINECO under grant CALPE (TIN2015-68608-R).

REFERENCES

Camunda Engine (2018) BPMN Workflow Engine, https://camunda.com/products/bpmn-engine/, accessed on 15 Dec 2018.

Camunda Modeler (2018) Design Workflows and Decisions, https://camunda.com/products/modeler/, accessed on 15 Dec 2018.

Camunda Services (2016) Get started with Camunda and CMMN 1.1, https://docs.camunda.org/get-started/cmmn11/, accessed on 15 Dec 2018.

Di Ciccio, C., Marrella, A., and Russo, A. (2014) Knowledge-intensive processes: characteristics, requirements and analysis of contemporary approaches, *Journal Data Semantics*, 4, 1, 29–57.

Hofmann, M., Betke, H., and Sackmann, S. (2015) Process-oriented disaster response management: a structured literature review, Bus. Process Manag. J., 21, 5, 966–987.

International Scout and Guide Fellowship (ISGF). (2017) Self Protection Handbook: Emergency Assistance, http://www.isgf.org/index.php/en/download/publications/our-kit/2817-8-emergency-2017/file, accessed on 28 Dec 2018.

Jul, S. (2007) Who's really on first? A domain-level user, task and context analysis for response technology, *In Proceedings of the 4th International Conference on Information Systems for Crisis Response and Management (ISCRAM) 2007*, 139-148.

Kurz, M., Schmidt, W., Fleischmann, A., et al. (2015) Leveraging CMMN for ACM: examining the applicability of a new OMG standard for adaptive case management. *In Proceedings of the 7th International Conference on Subject-Oriented Business Process Management*, 4.

Kushnareva, E., Rychkova, I., and Le Grand, B. (2015) Modeling business processes for automated crisis management support: lessons learned, *In Research Challenges in Information Science (RCIS), 2015 IEEE 9th International Conference on IEEE*, 388-399.

Nešković, S., and Kirchner, K. (2016) Using context information and CMMN to model knowledge-intensive business processes, *In Proceedings of the 6th International Conference on Information Society and Technology ICIST 2016*, 17-21.

Object Management Group (OMG). (2014) Case Management Model and Notation (CMMN) version 1.0, *https://www.omg.org/spec/CMMN/1.0/*, accessed on 10 Dec 2018.

Object Management Group (OMG). (2016) Case Management Model and Notation (CMMN) version 1.1, *https://www.omg.org/spec/CMMN/1.1/*, accessed on 11 Dec 2018.

Sánchez, J., Carsí J., y Penadés, M.C. (2015) Un entorno de gestión de casos para la resolución flexible de emergencias, ISSI-DSIIC, *Universidad Politécnica de Valencia*.

Shahrah, A. Y., & Al-Mashari, M. A. (2017) Modelling emergency response process using case management model and notation. *IET Software*, 11, 6, 301-308.

Van der Aalst, W. M. P., Weske, M., and Grünbauer, D. (2005) Case handling: A new paradigm for business process support, *Data & Knowledge Engineering*, vol. 53, 129-162.

Zensen, A., and Küster, J. (2018). A Comparison of Flexible BPMN and CMMN in Practice: A Case Study on Component Release Processes. *In 2018 IEEE 22nd International Enterprise Distributed Object Computing Conference (EDOC)*, 105-114.

Simulation of Crowd Response During Emergency Considering People's Rational and Irrational Thinking

Anying Chen
Institute of Public Safety Research, Department of Engineering Physics, Tsinghua University, Beijing, China; Beijing Key Laboratory of City Integrated Emergency Response Science, Beijing, China.
chenay15@mails.tsinghua.edu.cn

Guofeng Su*
Institute of Public Safety Research, Department of Engineering Physics, Tsinghua University, Beijing, China; Beijing Key Laboratory of City Integrated Emergency Response Science, Beijing, China.
sugf@tsinghua.edu.cn

Manchun Liang
Institute of Public Safety Research, Department of Engineering Physics, Tsinghua University, Beijing, China; Beijing Key Laboratory of City Integrated Emergency Response Science, Beijing, China.
lmc@mail.tsinghua.edu.cn

Shuijun He
Institute of Public Safety Research, Department of Engineering Physics, Tsinghua University, Beijing, China; Beijing Key Laboratory of City Integrated Emergency Response Science, Beijing, China.
13693355169@163.com

*Corresponding e-mail: sugf@tsinghua.edu.cn

ABSTRACT

Human beings have been facing numerous emergencies which could threaten their property or even their lives in all ages. In order to learn how people respond to the emergencies like earthquakes and fire disasters, a two-stage simulation considering people's rational thinking and irrational thinking was conducted. Results show that people's irrational thinking, like the herd effect, could exaggerate people's behavior of conformity, and it changes the spatial features that stronger herd effect leads to higher cohesion level. It is also worth mentioning that crowd response of condition of smaller population is harder to predict because of its instability, and the response of the very first part of people who make decisions could make great changes to the whole crowd's response. These results could give some enlightenment on the evacuation instruction during emergencies and future research works.

Keywords

Crowd response, evacuation, expected utility theory, herd effect.

INTRODUCTION

Emergencies, like sudden natural hazards, fire disasters, explosions and terrorist attacks, have been one of the major threats for human being's survival in history. By means of effective warnings people could reduce loss to a minimum extent before the scientists find ways to predict them earlier. While the final effectiveness of the warnings does not only depend on the development of science and technology, but also rests with people's rapid and correct responses.

The whole response process mainly includes warning receiving, decision-making and action taking. The warning receiving is a relatively objective process. It is closely related with the warning dissemination process,

including source, emitter, channel, receiver and sink according to Shannon and Weaver Model (Shannon, 1949). The decision-making process starts from people receiving the warning information and ends with their making up minds to take actions or decide not to take any action. In emergent cases, like fire disasters, this process decides whether people evacuate or not, when to evacuate, how to evacuate, where to evacuate, and with whom to evacuate. The action taking is a process making the decision made in the last stage come true. It's worth mentioning that these three stages are mutual fusion and integrated that in many cases people also keep receiving new warning or information, making or changing their decisions in the meanwhile when they are taking actions. In this research, the decision-making process is the main point of study.

The behavioral decision theory is one of the applicable method to explain people's decision making in theoretical way. It has been largely applied in financial problems, government decision-making, consumer behaviour, individual choices, emergency response, and many other fields (Prather and Middleton, 2006; O'Hare and Smitheram, 1995; Stahl and Harrell, 1981; Maguire and Albright, 2005; Fischhoff, 2010). The brought up of Expected Utility Theory by Von Neumann and Morgenstern has settled down the development direction of behavioral decision making theory under uncertain conditions (Neumann and Morgenstern, 1944), but it was challenged by several paradoxes because of its assumption of rational actor. Recent years the non-expected utility theory, among which the Prospect Theory is the most popular one, becomes prevailing in related research fields (Tversky, 1979). Until now many researchers are still making efforts to bring up new theories and methods within the framework of expected utility theory to describe people's decision-making process and fix the paradoxes that the expected utility theory could not solve. For example, introducing the uncertain theory to expected utility theory (Yao and Ji, 2014; Chen and Park, 2017); introducing extra parameters to achieve equivalent predictions as cumulative prospect theory (Charles-Cadogan, 2016); and proposing a construction-specific utility framework based on expected utility theory (Alozn and Galadari, 2017).

Some researches attempted to validate these theories by methods of experiments, and results showed that measures based on expected utility model obtained some degree of convergent validity and could be good predictors of actual market behavior (Smidts, 2000). While some doubted that expected utility theory failed to effectively predict people's behaviors and that the prospect theory was more consistent with the experiment results (Friedman, et al., 2014; Baillon and Bleichrodt, 2015). However, different voices were raised that the expected utility theory was revealed to be insignificantly different from other models and could satisfy all of the preferences the other theories could do (Hu, et al., 2012; Pettigrew, 2016). Abellan-Perpinan looked into the consistency of these theories in health area and found that the prospect theory was more consistent with rankings and choices but not not with intertemporal decisions compared with the expected utility theory (Abellan-Perpinan, et al., 2009). As concluded by Ivan Moscati, who reconstructed the trajectory of experimental researches of expected utility theory between 1950 and 1985, the flaws of EUT-based utility measurement do not undermine the utility measurement in general (Moscati, 2016).

Compared with the behavioral decision making theory which applies to individual decision making, crowd decision making seems more complex and unpredictable. Crowd behavior is one of the most popular research topics both in sociology and psychology fields, and by now there has been a number of representative findings that promote the researches' development. An important research about crowd behavior is Sherif's experiment of autokinetic phenomenon, demonstrating that individuals are easy to get affected by other people's suggestive influence (Sherif, 1936). Another typical research is Asch's conformity experiment revealing that social pressure from the majority of the group could exert influence on people's conformation behavior (Asch and Solomon, 1956). After that, researches related to crowd conformity behavior sprang up, especially in the field of financial behavior researches. A mass of researches investigated the stock markets around the world and proved the existence of herding behaviors, including the U.S.A., Japan, Germany, China,Turkish, and some other countries (Demirer, et al., 2014; Ashiya and Doi, 1999; Cakan and Balagyozyan, 2014; Babalos, et al., 2015; Yao, et al., 2014; Cajueiro and Tabak, 2009; Kremer and Nautz, 2013).

Researches specific to emergent occasions are much less in quantity compared with the researches of crowd behavior defined in common occasions,. There are several prominent theories should be mentioned, including Emergent Norm Theory, Inter-group perspective brought up by Reicher and Potter (Reicher and Potter, 1985), Model of Disorder brought up by Waddington (Waddington, 2010), Social Identity Theory brought up by Turner, Oakes, Haslam and McGarty (Turner et al., 1994), and Elaborated Social Identity Theory brought up by Reicher and Drury (Drury and Reicher, 1999). These theories provided frameworks for related researches to look further into crowd behaviors during emergencies. Empirical experiments also proved the existence of herding behavior during emergencies (Altshuler, et al., 2005; Wei, et al., 2014).

Recent researches also started to make efforts to discover the secrets hidden under people's herd behaviors. It was found that people's herd behavior depends on both environmental and personal factors, like the knowledge about the alternatives options, and that only under condition of certain level of uncertainty would the herd effect occur (Lovreglio, et al., 2016). Another perspective insists that the herd behavior does not applicable to all

emergencies, for example, people prefer not to follow the majority's escape route under crowded and no choice uncertainty conditions (Haghani and Sarvi, 2017). Some found that the herd behavior occurred when the individual interactions were strong (Chang, 2014). Based on these findings, researchers tried to establish qualitative and quantitative models to explain and analyze the herd behavior, like the sequential decision model (Banerjee, 1992; Morone, 2012), informational herding model (Cipriani and Guarino, 2014), and an asymmetric information and Baysian learning model (Hott, 2009).

The researches mentioned above are mostly qualitative and empirical studies. Based on these theories, many researchers have built up various quantitative models to simulate people's behaviour during emergencies, mostly focusing on people's evacuation process, such as pedestrian behaviour, evacuation time, jamming phenomenon, bottleneck effect and so on. Some prominent researches include Helbing's research integrating panic behaviour and quantitative theories published in Nature (Helbing et al., 2002), Burstedde's simulation of pedestrian dynamics using a two-dimensional cellular automaton (Burstedde et al., 2001), Kirchner's simulation of pedestrian dynamics using a bionics-inspired cellular automaton model (Kirchner and Schadschneider, 2002), and some other related researches (Luo et al., 2008; Zaharia, 2009; Wu, 2014; Wagner, 2014).

In summary, to describe people's individual decision-making under rational thinking, the expected utility theory could be a relatively effective method in spite of its defects in explaining some paradoxes. On the other hand, the influence of surrounding people was proved to be existing, which makes the crowd to show a tendency of irrational herding behavior, and eventually make great differences on people's evacuation results. However, the quantitative researches of people's response during emergency are not many, among which mostly focusing on the evacuation process, but not much on the decision-making process before people take actions of evacuation. In this research a two-stage simulation was conducted integrating people's rational thinking of individual risk perception based on expected utility theory and irrational thinking affected by herd effect using method of cellular automaton in order to study people's possible response under different conditions, and some meaningful findings were put forward.

MODEL AND SIMULATION DESIGN

From the angle of complex adaptive system, cellular automaton (CA) could simulate the emergent feature of systems by constructing cellulars at the microcosm level and designing rules for the cellulars to interact. Now it has been widely used to simulate the social system, especially people's evacuation processes during emergencies. A cellular automaton model could be defined by a quadruple form, donated by $CA = (S, X, V, f)$, where S is cellular space, X for cellular states, V for cellular neighborhood, and *f* for transition rules of cellular states. It is suitable for simulating people's decision-making process because of the following reasons:

1. The limited cellular space in CA model is consistent with the indoor environment where the decision-making processes usually happen in real world.

2. Cellular states could reflect each individuals properties during decision-making, like decision intention, decided or not and evacuate or not.

3. Cellular neighborhood explains who exert an influence on the cellular's decision and the transition rule explains how they make the influence happen.

While the normal cellular automaton could only simulate homogeneous properties and distribution that all cellulars obey the same rule and are located orderly, which do not fit in the real social system. By integrating the method of Agent-based Model (ABM) it could well solved these problems for its feature of heterogeneity. So here we use the CA settings to simulate people's decision-making but use the ABM method to realize the simulation processes with heterogeneity.

Assume that there are people amount of N regularly located in an indoor environment, like a classroom, an office or a concert hall. The whole simulation includes two stages, corresponding to people's decision intention and interaction processes.

1. Decision intention (rational process).

Once the emergency alarm rings, for example, the fire alarm or an earthquake early warning, individuals first form their decision intention, to make it simple, of evacuate or not, and basically it is a relatively rational process. In financial researches, the expected utility theory was widely used to describe how people make choices based on potential gains and losses, which could also be utilized to calculate people's decision-making intention under emergency conditions. The following table describes the payoff matrix of each individual choosing to evacuate and not evacuate under the circumstances of true alarm and false alarm.

Table 1. Payoff Matrix of Evacuation Intention

Payoff	True	False
Evacuate	a_i	b_i
Not evacuate	c_i	d_i

According to the expected utility theory, the expected utility is given by

$$U = p_1 u(x_1) + p_2 u(x_2) \tag{1}$$

Let $p_i (0 \le p_i \le 1)$ be the perceived probability of emergency happening of individual *i*. So the value function of each individual *i* is given by

$$U_i(evacuate) = p_i a_i + (1 - p_i) b_i \tag{2}$$

$$U_i(not - evacuate) = p_i c_i + (1 - p_i) d_i \tag{3}$$

Assume that the evacuation intention was entirely decided by the expected utility. Let

$$U_i = U_i(evacuate) - U_i(not - evacuate) \tag{4}$$

then

$$y_i = \begin{cases} 1(evacuate) & U_i > 0 \\ 0(not - evacute) & U_i \le 0 \end{cases} \tag{5}$$

2. Interaction (irrational process).

In order to simulate people's herd behavior, in other words, imitating the majority's behavior, which is an irrational process, the assumption that people's final decision could be affected by the decisions of other people was inserted. Let V_i be the neighbourhood of individual i. We assume that individual *i* might get affected by the proportion of people decided to evacuate in the range of V_i. Let $q_i (0 \le q_i \le 1)$ be the potential of being influenced by others, λ_i be the proportion of people decided to evacuate in the neighbourhood range of V_i.

If individual *i* is not influenced by others, the probability of evacuating is totally decided by the individual's evacuate intention. If individual *i* is totally irrational and influenced by others, the probability of evacuating is decided by the herd effect.

$$E(q = 0) = u \tag{6}$$

$$E(q = 1) = \lambda \tag{7}$$

So the probability of individual *i* to decide to evacuate is given by

$$E = (1 - q)u + q\lambda \tag{8}$$

The above model takes people's expected utility as the reference point of herd effect. If individual *i*'s evacuation rate is larger than his/her value function, the probability of evacuating will increase, and vice versa. While another idea is to take the majority's decision as the reference point, in other words, if the majority in the range of V_i choose to evacuate, individual *i*'s evacuate rate would go up, indicating that

$$E = u + cq(\lambda - 0.5) \tag{9}$$

where *c* is a constant decided by *u*.

For the condition that $\lambda - 0.5 \ge 0$, a boundary condition is that

$$E = 1, \text{ when } q = 1, \lambda = 1. \tag{10}$$

So

$$c = 2(1 - u), \quad E = u + 2q(1 - u)(\lambda - 0.5). \tag{11}$$

For the condition that $\lambda - 0.5 < 0$, a boundary condition is that

$$E = 0 \text{, when } q = 1, \lambda = 0. \tag{12}$$

So

$$c = 2u \text{, } E = u + 2uq(\lambda - 0.5). \tag{13}$$

So when the reference point is the majority's decision, the calculation function is:

$$E = \begin{cases} u + 2q(1-u)(\lambda - 0.5) & \lambda \text{-} 0.5 \geq 0 \\ u + 2uq(\lambda - 0.5) & \lambda \text{-} 0.5 < 0 \end{cases} \tag{14}$$

An important factor that could make change to people's decision is their decision time. Some people make decisions very quickly that they do not need to observe others decisions to make decisions, while some might need to refer to all other people's decisions to make their own ones. So we assume that people's decision time satisfies a normal distribution $T \sim N(t, \sigma^2)$, that is,

$$f(t) = \frac{1}{\sqrt{2\pi}\sigma} \exp(-\frac{(t - t_0)^2}{2\sigma^2}) \tag{15}$$

where t_0 is the mean observing time for all individuals.

SIMULATION RESULTS

The simulation was conducted on Netlogo 5.3.1. In order to simplify the simulation, the following variables were assumed to be normally distributed:

Perceived reliability of warning: $p \sim N(p_0, \sigma^2)$.

Probability of being influenced by others: $q \sim N(q_0, \sigma^2)$.

Considering that simulation of larger population could narrow the simulation errors with little influence on the simulation results, the total population was set to be ten thousand for each simulation. The value of a_i, b_i, c_i and d_i in Table 1 were set to be non-dimensional numbers ranged from 0 to 10 with initial value of 5, representing the neutral attitude towards all the losses. According to Equation (2), (3) and (4), the effective variables that changes the utility could be simplified to (a-c) and (b-d). Further simplification is conducted to set (b-d) equals zero and (a-c) varies from -10 to 10 when concerning the changes of payoff evaluation.

In order to study the time-dependent characteristics of evacuating decision-making, the variables were set to be a set of values which could roughly reflect the tendency of evacuation rate curve, and changes of these values would not make difference on the shape of the curve (Table 2).

It is easy to find that the frequency curve for people who decided to evacuate and not to evacuate goes up slowly in the beginning, and starts to explosively grow with time goes, and finally reaches to the maximum with slower and slower speed. The burst of decided people could be due to the normally distributed decision time, or the herd effect of imitating others behavior.

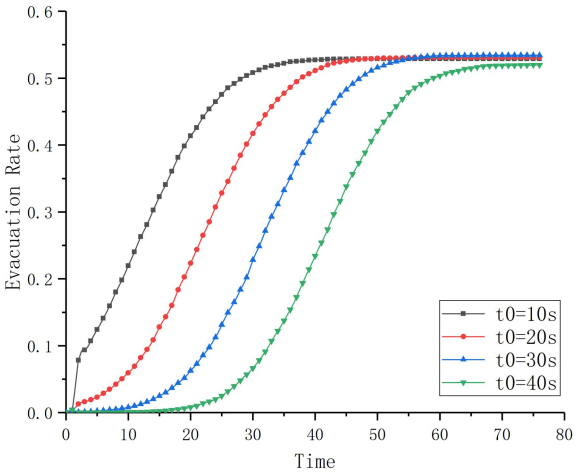


Figure 1. Evacuation Rate of Different Decision time

Firstly, the influence of decision time is evaluated and people's mean decision time (t_0 in Equation (15)) is set to be 10 seconds to 40 seconds. It is obvious that the mean decision time of the crowd does not make a difference on the final evacuation rate or the rising tend except the equidistant x-offest of the curves. A small detail could be found in the graph that at the very first time people make evacuation decisions in the condition of very short decision time, the curve is not smooth but connected by an inflection point. This phenomenon could be attribute to the large gap between the actual evacuation population at the first point and the supposed evacuation population with normally distributed decision time.

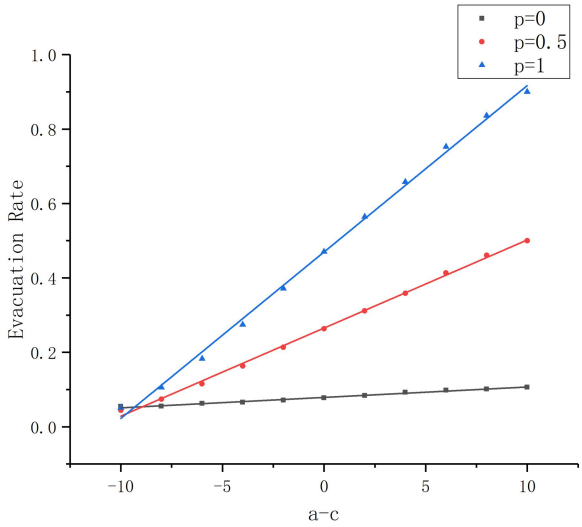


Figure 2. Evacuation Rate of Different Warning Reliability

It is intelligible that evacuation rate was a linear function of utility if we set the conformity level to be zero to minimize the influence of herd effect. While this linear tendency could be affected by the warning information that the evacuation rate of different warning reliability (p_i in Equation (2) and (3)) is simulated. As shown in Figure 2, with more reliable warning, more people would choose to evacuate, which is accorded to our assumption and previous researches on warning reliability (Meyer and Joachim, 2001; Roy et al., 2015).

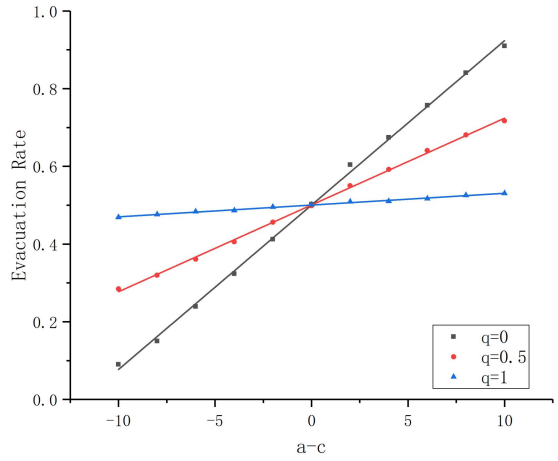


Figure 3. Evacuation Rate of Different Conformity Level (utility as reference point)

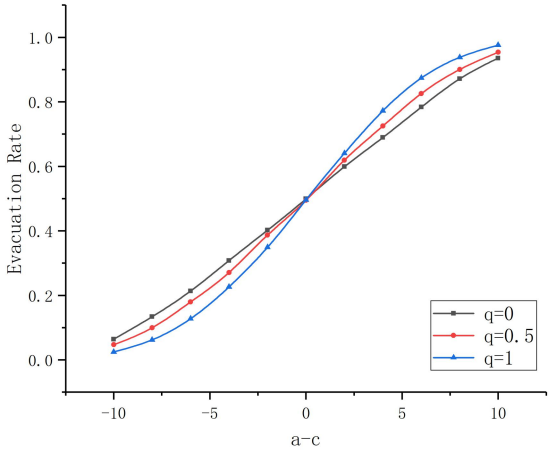


Figure 4. Evacuation Rate of Different Conformity Level (0.5 as reference point)

Besides, the herd behavior could also change people's evacuation decision as Figure 3 and Figure 4 show. If we employ the model of setting individuals' value function as comparison point (Equation (8)), it is found that when the value of utility is larger than zero, the stronger the herd effect is, the lower the evacuation rate could be. On the contrary, when the utility is lower than zero, the stronger the herd effect is, the higher the evacuation rate is. Though this result could be explained by mathematical analysis of Equation (8), it is not corresponding to our common sense. While if we employ the other model which takes the majority's decision as reference point (Equation 14), more reasonable results are found. Contrary to the result of the other model, when people's value function is larger than zero, the stronger the herd effect is, the higher the evacuation rate is. This result is consistent with both our common sense and previous findings (Helbing et al., 2000; Herbst and Mas, 2015). And an information acquired from the figure is that this kind of amplification effect is not same for each utility. For example, it reaches the most obvious point when the expected utility function equals 5 and -5, and least obvious at the zero point and the two ends of the utility function due to the limitation of the maximum evacuation rate.

The comparison of patterns of the crowd's final decision is more visualized. When there is no herd effect, the pattern of decision-making is quite dispersive because people make their decisions only based on their utility, which is totally not affected by others decisions. While for the strong herd effect condition, the pattern of decision-making changes to a relatively conterminous mode, because people do not make their decisions based on their heterogeneous utility but their neighbors' decision.

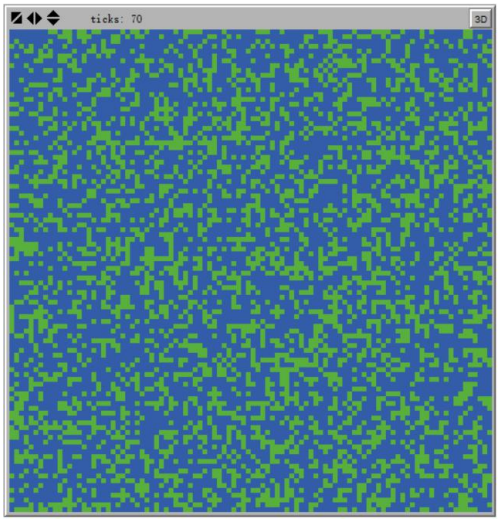


Figure 5. Spatial Pattern of Weak Conformity Level

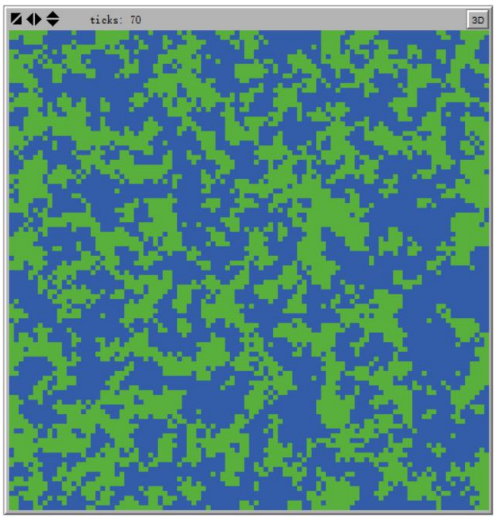


Figure 6. Spatial Pattern of Strong Conformity Level

Another finding is that if we change the neighborhood selection strategy from Moore neighborhood to the global viewing angle, which means each individual could observe all people in the same space and imitate their

behaviour, the decision pattern gets dispersal again and it doesn't change with the herd effect getting stronger. While this scenario is not realistic because people do not have the ability to observe all ten thousand neighbors in the same space. In most cases, people could only observe neighbors around them within their vision.

In order to evaluate crowd's dispersivity level, the definition of centrality and centralization potential in the field of social network are employed here (Freeman, 1979). Centrality measures the degree to which one node in a network is connected to all other nodes, and the centralization measures the concentrative degree of the whole network, which is decided by the centrality of all nodes. It's defined by

$$C = \frac{\sum (C_{\max} - C_i)}{\max[\sum (C_{\max} - C_i)]}, \tag{16}$$

where C_i represents the centrality of individual i and $C_{\max}$ represents the maximum centrality of all people. According to the simulation result, the centralization mode is quite different for different neighborhood selection strategies. The calculation result shows that the centralization does not change according to people's conformity level when all other agents are set to be agent i's neighbors. But things change when the neighborhood is set to be the Moore neighbors that the centralization level is negatively linear with the conformity level, in other words, higher conformity level leads to higher cohesion.

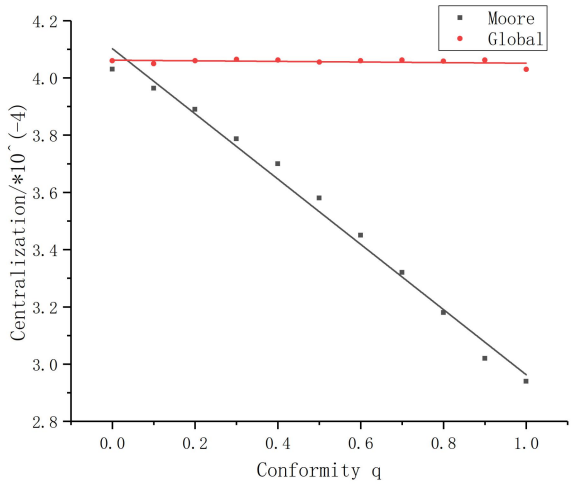


Figure 7. Evacuation Rate of Different Neighborhood

Above results are obtained under the condition of ten thousand population in a certain space, while it is not a common scenario to have such a large event held in a site able to accommodate ten thousand people. Theoretically, the average evacuation rate of simulations repeat times without number should be the same no matter how many numbers of people, but the result could change if we only repeat limited times. If we take the situation of complete herd effect as an example, theoretically the average evacuation rate should be around 0.5. From the simulation result, we can see that with the population going up, the average evacuation rate gets closer to to theoretical value, and the stability gets higher for the shorter length of variation range. While for smaller population cases, especially for the 25 people group, the median and average evacuation rate was almost 10% away from the theoretical value. And for the the extreme cases, the evacuate rate could be lower than 0.3 and higher than 0.6. This kind of case variation is due to the small sample size of each case. In many scenarios, there are only tens of people or even less than 10 people in a room, like classrooms and offices, so people's decision under emergency condition could have quite different results.

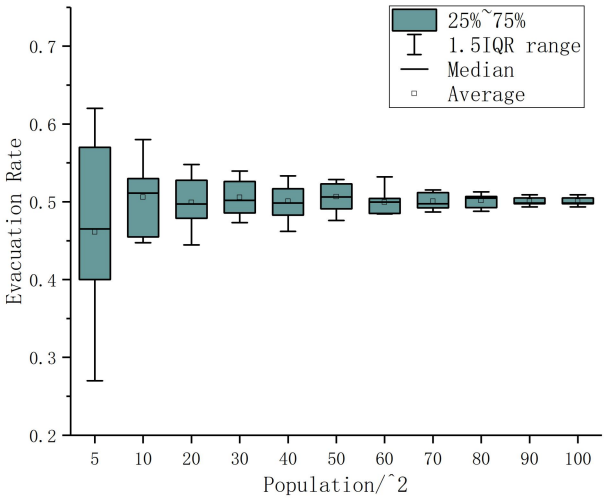


Figure 8. Evacuation Rate of Different Population

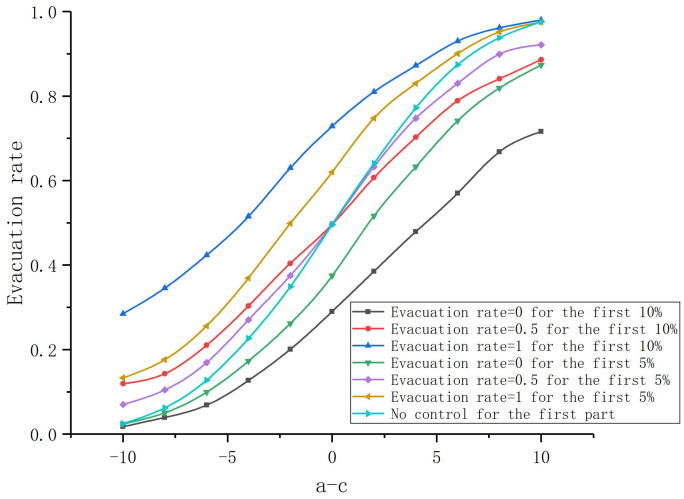


Figure 9. Evacuation Rate When Controlling the First 5% People and the First 10% People

Based on Equation (14) and the previous researches on herd effect, neighbors who first make decisions could have great impact for the others. In this simulation, the influence of the first 5% and 10% parts of neighbors who make decisions are studied. According to the simulation result, higher evacuation rate of neighbors who make decision first could effectively raise individuals' final evacuation rate. For example, when people is irresolute on whether to evacuate or not (utility=0), if all of the first 5% neighbors make decisions to evacuate, the total evacuation rate could raise by 20%, and by 40% for the condition of the first 10% neighbors decide to evacuate. Similar results could be found when the first part of neighbors decide not to evacuate. And this effect is particularly significant when individuals' first evacuation intention is quite low that the total evacuation rate could raise over 5 times and even 10 times. This remarkable effect is consistent with Dyer's empirical experiment of leadership effect in crowd decision-making (Dyer et al., 2008) and could be taken advantages in evacuation strategies during emergencies.

The variable settings of the above simulation were presented in Table 2.

Table 2. Variable Settings in Each Simulation

No.	Independent Variable	Corresponding Figure	a-c	b-d	warning reliability p	Conformity Level q
1	Decision time	Figure 1	4	-4	0.6	0.5
2	Warning reliability	Figure 2	-10~10	0	0, 0.5, 1	0

3	Conformity level	Figure 3 and 4	-10~10	0	1	0, 0.5, 1
4	Neighborhood	Figure 7	0	0	1	0~1
5	Population	Figure 8	0	0	0.5	0.5
6	Controlled evacuation rate for the first 5% and 10% people	Figure 9	-10~10	0	1	1

DISCUSSION

According to the simulation results, the shapes of the evacuation decision-making curve do not change when the decision-making mean time changes. But the changes in the position of coordinate axes show the importance of the decision-making timing. For example, the lead time of a sever earthquake usually lies between seconds to tens of seconds. For a 20-second earthquake early warning, people need to make decisions of evacuate or not in 20 seconds, so it would be quite dangerous for crowds whose decision time was normally distributed with average of 20 seconds, 30 seconds or even more. Now that the great differences of the final results in limited time with different decision time have emerged, some other questions about the decision timing should be studied. What decides people's decision-making time? Is it decided by personal characteristics, surroundings, warning information or other people's behavior? How to shorten people's decision-making time while keeping people to be rational under emergent condition? These questions could be looked into by experiments or real cases analysis and the answers to these questions could be of great importance on decreasing emergency losses.

In this simulation, we assume that the expected utility is decided by the alarm's reliability and people's payoff matrix. It is easy to understand that when the utility is over zero, people's evacuation rate goes up with the alarm reliability getting higher. So it is of importance to improve the warning's reliability but it is still unknown that how to evaluate the alarm's reliability and how to match the public's perceived reliability and the authority's technical reliability.

It is also feasible to raise people's evacuation rate by changing their payoff matrix, in other words, increasing people's benefits of evacuating (decreasing people's losses of evacuating) or decreasing people's benefits of not evacuating (decreasing people's losses of not evacuating). For the first circumstance, measures of improving evacuating convenience and increasing compensation for emergency losses could be conducted, for example, designing and constructing more convenient escape ways and increasing the compensation rate for people who take positive actions to reduce losses. For the second circumstance, the government and related departments could increase people's subjective evaluation of emergency losses by improving emergency education to help people realize the severe consequence it could result in. Apart from understanding how to improve people's response during emergencies, researches should also study further on the formation of people's payoff evaluation. For example, what kinds of factors result in people's differences of payoff evaluation? Is there any way to change people's payoff matrix, and further to change people's decision-making under emergent occasions?

As the results show in the last section, people's final decisions could be largely influenced by the first part of people who make decisions because of herd effect. Usually people are criticizing the herd effect because herd effect is a kind of expression of irrational thinking, but sometimes we can also utilize this irrational thinking to reach a better consequence. There is a great probability that people might not make an objective decision by their rational thinking, resulting in the gap between their real decision and the authorities' expected decision. Under this circumstance, if people who make decisions first could make correct decisions, and then the others, who do not have a reasonable evaluation of evacuation payoff, could just imitate others correct behavior with less considering the incorrect analysis of themselves, improving the final results for the whole. While opposite things could also happen that people who could make correct decisions are influenced by people who make incorrect decisions, worsening the emergency consequence. So the authority could find ways to educate or induce people who make decisions most quickly or other people who could largely insert influences on others to make correct decisions to narrow the gap between expected response and real response. So now the problem is detailed to be the problem of people who make their decisions quickest: What kinds of factors decide people's decision time and who are probably the one who make decisions earliest? Apart from the timing of making decisions, what else could be the influencing factors for the crowd, such as the social relationship? And ultimately how can we utilize people's psychology of herd effect to improve people's emergency behavior? In a word, there are still too many ignorant questions to be dug out.

Another important factor in this simulation is the neighborhood selection strategy. From our simulation result, the smaller neighborhood range could make crowd's cohesion level higher. Though it seems not useful for the

final evacuation decision rate, it could eventually affect people's evacuation process. Crowd of higher cohesion level are more likely to create congestion in the evacuation route and crowd of lower cohesion are more likely to avoid congestion because their dispersive decision pattern. While when the population is large or part of the room space is shielded, it is not possible for human eyes to observe all people in the same space because of the limited vision field or their personal psychological condition. So here comes the questions: How large should people's neighborhood range be? Is it only limited to people's vision field? Do all people usually set their observation range fixed or do they change according to people with different personal characteristics?

CONCLUSION

The simulation provides a method to simulate crowd's decision-making condition taking people's rational evaluation and irrational thinking into consideration respectively in two stages. The results show that the reliability of the alarms and the herd effect could have great influences on people's decision-making during emergencies, and the control of part of people who make decisions first could help the manage departments to command the emergency condition to an expected way. These results support the findings of previous researches on warning reliability, herd effect and leadership effect.

Based on the above findings, several measures reducing the emergency loss are put forward, including reducing people's decision time, improving warning's reliability, improving evacuating convenience and compensation for emergency losses, improving emergency education to help people realize the severe consequence it could result in, finding ways to educate or induce people who make decisions most quickly or other people who could largely insert influences on others to make correct decisions.

However many questions related to people's decision time, warning reliability and conformity behavior are still unknown in this field. The research questions mentioned in discussion section are all deserve to look deeper into and could help people learn more on crowd behaviors during emergencies, and reduce people's property loss and possible casualty in the end.

This work was supported by the the Program of National Public Emergency Response Platform of China (2018YFC0807000).

ACKNOWLEDGMENTS

This work was supported by the Program of National Public Emergency Response Platform of China (2018YFC0807000).

REFERENCES

Abellan-Perpinan, J. M., Bleichrodt, H., & Pinto-Prades, J. L. (2009). The predictive validity of prospect theory versus expected utility in health utility measurement. *Journal of Health Economics*, *28*(6), 1039-1047.

Alozn, A. E., & Galadari, A. (2017, August). Utility function under decision theory: A construction arbitration application. In *AIP Conference Proceedings* (Vol. 1867, No. 1, p. 020001). AIP Publishing.

Altshuler, E., Ramos, O., Núñez, Y., Fernández, J., Batista-Leyva, A. J., & Noda, C. (2005). Symmetry breaking in escaping ants. *The American Naturalist*, *166*(6), 643-649.

Asch, S. E. (1956). Studies of independence and conformity: I. A minority of one against a unanimous majority. *Psychological monographs: General and applied*, *70*(9), 1.

Ashiya, M., & Doi, T. (2001). Herd behavior of Japanese economists. *Journal of Economic Behavior & Organization*, *46*(3), 343-346.

Babalos, V., Balcilar, M., & Gupta, R. (2015). Herding behavior in real estate markets: novel evidence from a Markov-switching model. *Journal of Behavioral and Experimental Finance*, *8*, 40-43.

Baillon, A., & Bleichrodt, H. (2015). Testing ambiguity models through the measurement of probabilities for gains and losses. *American Economic Journal: Microeconomics*, *7*(2), 77-100.

Banerjee, A. V. (1992). A simple model of herd behavior. *The quarterly journal of economics*, *107*(3), 797-817.

Burstedde, C., Klauck, K., Schadschneider, A., & Zittartz, J. (2001). Simulation of pedestrian dynamics using a two-dimensional cellular automaton. *Physica A Statistical Mechanics & Its Applications, 295*(3), 507-525.

Cajueiro, D. O., & Tabak, B. M. (2009). Multifractality and herding behavior in the Japanese stock market. *Chaos, Solitons & Fractals*, *40*(1), 497-504.

Cakan, E., & Balagyozyan, A. (2014). Herd behaviour in the Turkish banking sector. *Applied Economics*

Letters, *21*(2), 75-79.

Chang, S. K. (2014). Herd behavior, bubbles and social interactions in financial markets. *Studies in Nonlinear Dynamics and Econometrics*, *18*(1), 89-101.

Charles-Cadogan, G. (2016). Expected utility theory and inner and outer measures of loss aversion. *Journal of Mathematical Economics*, *63*, 10-20.

Chen, X. , & Park, G. K. . (2017). Uncertain expected utility function and its risk premium. *Journal of Intelligent Manufacturing, 28*(3), 581-587.

Cipriani, M., & Guarino, A. (2014). Estimating a structural model of herd behavior in financial markets. *American Economic Review*, *104*(1), 224-51.

Demirer, R., Kutan, A. M., & Zhang, H. (2014). Do ADR investors herd?: Evidence from advanced and emerging markets. *International Review of Economics & Finance*, *30*, 138-148.

Drury, J., & Reicher, S. (1999). The intergroup dynamics of collective empowerment: substantiating the social identity model of crowd behavior. *Group Processes & Intergroup Relations, 2*(4), 381-402.

Fischhoff, B. (2010). Strategic policy preferences: a behavioral decision theory perspective. *Journal of Social Issues, 39*(1), 133-160.

Freeman, L. C. . (1979). Centrality in social networks' conceptual clarification. *Social Networks, 1*(3), 215-239.

Friedman, D. , Isaac, R. M. , James, D. , & Sunder, S. . (2014). Risky curves: on the empirical failure of expected utility. *Social Science Electronic Publishing*.

Haghani, M. , & Sarvi, M. . (2017). Following the crowd or avoiding it? empirical investigation of imitative behaviour in emergency escape of human crowds. *Animal Behaviour, 124*, 47-56.

Helbing, D., Farkas, I. J., & Vicsek, T. (2000). Simulating dynamical features of escape panic. *Nature, 407*(6803), 487-90.

Herbst, D. , & Mas, A. . (2015). Peer effects on worker output in the laboratory generalize to the field. *Science, 350*(6260), 545-549.

Hott, C. (2009). Herding behavior in asset markets. *Journal of Financial Stability*, *5*(1), 35-56.

Hu, G. , Sivakumar, A. , & Polak, J. W. . (2012). Modelling travellers' risky choice in a revealed preference context: a comparison of eut and non-eut approaches. *Transportation,39*(4), 825-841.

Kirchner, A., & Schadschneider, A. (2002). Simulation of evacuation processes using a bionics-inspired cellular automaton model for pedestrian dynamics. *Physica A Statistical Mechanics & Its Applications,312*(1), 260-276.

Kremer, S., & Nautz, D. (2013). Short-term Herding of Institutional Traders: New Evidence from the German Stock Market. *European Financial Management*, *19*(4), 730-746.

Loomes, G. , & Sugden, R. . (1982). Regret theory: an alternative theory of rational choice under uncertainty. *Economic Journal, 92*(368), 805-824.

Lovreglio, R., Fonzone, A., dell'Olio, L., & Borri, D. (2016). A study of herding behaviour in exit choice during emergencies based on random utility theory. *Safety science*, *82*, 421-431.

Luo, L. , Zhou, S. , Cai, W. , Low, Y. H. , & Chen, D. . (2008). Agent-based human behavior modeling for crowd simulation. *Computer Animation and Virtual Worlds, 19*(3-4), 271-281.

Maguire, L. A. , & Albright, E. A. . (2005). Can behavioral decision theory explain risk-averse fire management decisions?. *Forest Ecology and Management, 211*(1-2), 0-58.

Meyer, & Joachim. (2001). Effects of warning validity and proximity on responses to warnings. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43*(4), 563-572.

Morone, A. (2012). A simple model of herd behavior, a comment. *Economics Letters*, *114*(2), 208-211.

Moscati, I. (2016). Expected utility theory and experimental utility measurement, 1950–1985. from confidence to scepticism. *The European Journal of the History of Economic Thought*.

Neumann, J. V. , & Morgenstern, O. . (1944). *The Theory of Games and Economic Behaviour*. Princeton University Press.

O'Hare, D. , & Smitheram, T. . (1995). 'pressing on' into deteriorating conditions: an application of behavioral decision theory to pilot decision making. *International Journal of Aviation Psychology, 5*(4), 351-370.

Pettigrew, R. G. . (2016). Risk, rationality, and expected utility theory. *Canadian Journal of Philosophy, 45*(5-6), 798-826.

Prather, L. J., & Middleton, K. L. (2006). Timing and selectivity of mutual fund managers: an empirical test of the behavioral decision-making theory. *Journal of Empirical Finance, 13*(3), 249-273.

Reicher, S. & Potter, J. (1985). Psychological theory as intergroup perspective: a comparative analysis of "scientific" and "lay" accounts of crowd events. *Human Relations, 38*(2), 167-189.

Roy, C., Sarkar, S. K., Åberg, J., & Kovordanyi, R. (2015). The current cyclone early warning system in Bangladesh: Providers' and receivers' views. *International journal of disaster risk reduction*, *12*, 285-299.

Sherif, M. (1936). The psychology of social norms.

Smidts, P. A. . (2000). Assessing the construct validity of risk attitude. *Management Science, 46*(10), 1337-1348.

Stahl, M. J., & Harrell, A. M. (1981). Modeling effort decisions with behavioral decision theory: toward an individual differences model of expectancy theory. *Organizational Behavior & Human Performance,27*(3), 303-325.

Turner, J. C. , Oakes, P. J. , Haslam, S. A. , & Mcgarty, C. . (1994). Self and collective: cognition and social context. *Personality and Social Psychology Bulletin, 20*(5), 454-463.

Tversky, K. A. . (1979). Prospect theory: an analysis of decision under risk. *Econometrica, 47*(2), 263-292.

Waddington, D. (2010). Applying the flashpoints model of public disorder to the 2001 bradford riot. *British Journal of Criminology, 50*(2), 342-359(18).

Wagner, N. , & Agrawal, V. . (2014). An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster. *Expert Systems with Applications,41*(6), 2807-2815.

Wei, J., Zhou, L., Wei, Y., & Zhao, D. (2014). Collective Behavior in Mass Incidents: a study of contemporary China. *Journal of Contemporary China*, *23*(88), 715-735.

Wu, S. , & Sun, Q. . (2014). Computer simulation of leadership, consensus decision making and collective behaviour in humans. *PLOS ONE, 9*.

Yao, J., Ma, C., & He, W. P. (2014). Investor herding behaviour of Chinese stock market. *International Review of Economics & Finance*, *29*, 12-29.

Yao, K. , & Ji, X. . (2014). Uncertain decision making and its application to portfolio selection problem. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 22*(01), 113-123.

Zaharia, M. H., Leon, F., Pal, C., Pagu, G., Baykara, N., & Mastorakis, N. (2009, May). Agent-based simulation of crowd evacuation behavior. In *WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering* (No. 11). World Scientific and Engineering Academy and Society.

A Preliminary Optimisation-based Approach to Coordinate the Response of Ambulances in Mass Casualty Incidents

Haya Aldossary
Newcastle University
h.aldossary2@newcastle.ac.uk

Graham Coates
Newcastle University
graham.coates1@newcastle.ac.uk

ABSTRACT

Mass Casualty Incidents (MCIs) may occur with no notice and require a rapid response to manage the casualties and arrange their transportation to hospitals. MCIs may result in different numbers of casualties and fatalities. Further, response time can play a crucial role in reducing fatalities and protecting lives. This paper reports on a preliminary optimisation-based approach, termed MCIER, which has been developed to co-ordinate the response of ambulances to multiple MCIs. In this approach, a realistic representation of the road network is modelled for the geographical area of interest. Also, a Neighbourhood Search Algorithm (NSA) has been developed in order to find the optimum solution to the problem under consideration. A hypothetical case study of a MCI in Newcastle-upon-Tyne has been considered to investigate the effect on response time of the time of day, and day of week, on which the incident occurs.

Keywords

MCIs, Optimization-based approach, Co-ordination, Emergency response.

INTRODUCTION

Disasters, which can be classified as natural or man-made, can occur in a short time and cause widespread damage to infrastructure, humans, fauna and flora (Pereira *et al.*, 2011). Natural disasters may occur from severe natural phenomena such as floods, earthquakes and volcanoes (Lowes & Cosgrove, 2016). For example, the earthquake in Kashmir, northern Pakistan in 2005, killing 90,000 and injuring 110,000, and the Indonesia flood in 1815, killing 92,000 (Mackway-Jones & Wiley, 2012). However, man-made disasters may include deliberate terrorist activity (Mackway-Jones & Wiley, 2012) and can occur in places where a large number of people are present. Both natural and man-made disasters may result in significant loss of life (Centre of Trauma Sciences, 2016; Department of Health, 2007; NHS England National Emergency Preparedness Resilience and Response Unit, 2015; The UK Cabinet Office, 2017) which can be referred to as Mass Casualty Incidents (MCIs) (Lowes & Cosgrove, 2016). MCIs can result in different numbers and conditions of casualties, and numbers of fatalities, and thus the medical needs and the response plans required can be different (Frykberg, 2002).

The emergency response to a major incident involves the emergency services (ambulance, fire, and police) and hospitals, which need to work together and co-ordinate their activities to meet strategic goals (The UK Cabinet Office, 2017) such as protecting lives, minimising fatalities and reducing suffering. Therefore, the emergency response may require extra co-ordination and extraordinary resources (Lowes & Cosgrove, 2016; Mackway-Jones & Wiley, 2012). Further, MCIs pose challenges including high uncertainty, time pressure, a shortage of staff and, interdependencies and interconnections between multiple services and responders involved (Department of Health, 2007; Yi & Kumar, 2007; Lerner *et al.*, 2008; Mete & Zabinsky, 2010; Wex *et al.*, 2012).

Co-ordination issues that are relevant in MCIs are discussed in (Malone & Crowston, 1994; Chen *et al.*, 2008). Task allocation, or task flow, is one of these issues related to assigning tasks to the right responders to avoid overlapping and duplicating effort (Jotshi *et al.*, 2009; Amram *et al.*, 2012; McCormack & Coates, 2015). Variations of task scheduling are considered in (Gong & Batta, 2007; Jotshi *et al.*, 2009; Amram *et al.*, 2012;

Wilson *et al.*, 2013a; Repoussis *et al.*, 2016). For example, Wilson et al. (2013a) have considered task scheduling where each casualty is assigned to a specific hospital. Further, each responder is given a set of inter-dependent tasks related to the type of injury of a casualty. Repoussis et al. (2016) assumed that a limited number of tasks is assigned to each ambulance where the duration of each task is assumed to be known. Wilson et al. (2013a) and Repoussis et al. (2016) have modelled the stochastic travel time of the ambulances as a normally distributed random variable. They referred to the mathematical model suggested by (Kolesar *et al.*, 1975), and was extended in (Budge *et al*., 2010), where two equations are provided, each of which is used to calculate the travel time based on the type of the journey, i.e. long or short journey. However, the time and day of the occurrence of the incident are neglected which could have a negative impact on the response. Further, the prediction of the travel times of ambulances in urban environments, as modelled in the work presented in (Wex *et al.*, 2012), could be difficult to assume as such environments may be subjected to severe traffic.

Another co-ordination issue, as alluded to above, is casualty transportation. In MCIs, transportation involves transferring the right casualty to the right hospital at the right time using the right emergency vehicle. Modelling a realistic representation of a road network of the geographical area of interest, to be used by emergency vehicles during the MCI, is essential in order to design an accurate response plan. During a MCI, the road network might be affected negatively due to severe traffic, such as congestion, which may cause a delay in the response. A simplistic road network has been presented in (Amram *et al.*, 2012; Zhang *et al*, 2012; Muaafa *et al*., 2014; Repoussis *et al.*, 2016; Kamali *et al.*, 2017) where distances and the travel times between two locations in MCIs are assumed to be known upon model initialization. A realistic representation of the road network within the problem environment is represented in (Hawe *et al.*, 2015) with a sufficient level of detail, e.g. length and type of roads.

Considering the actual distance between two locations and constant speed are insufficient to predict the travel time where there are other factors, such as the type of road, the time of day, which could have an impact on driving in a normal and MCI situations. Dong et al. concluded that the type of road has a minor impact on the overall travel time. Further, the time of the day is conducted to have a minor effect in (Kolesar *et al.*, 1975; Budge *et al.*, 2010; Wilson *et al.*, 2013; Repoussis *et al*., 2016). In contrast, Schmid *et al.* (2010) reported that vehicles, including ambulances, would be affected by the increasing volume of traffic during the peak time which causes congestion. McCormack *et al*. (2015) established that the time and day has a significant impact on the speed of ambulance vehicles.

As mentioned, the focus of the research presented in this paper is on major incidents such as that of the bombings in multiple London sites in 2005 (London Assembly, 2006). Man-made disasters, such as terrorist attacks, occur with no-notice where the majority of such attacks predominantly take place in urban areas which can be densely populated. As such, a preliminary optimization-based approach (MCIER) has been developed incorporating a Neighbourhood Search Algorithm and a realistic representation of the road network in any geographical area of interest. Further, the traffic congestion is modelled by changing the speed of the ambulance vehicles based on the traffic at a particular time and on a specific day with the objectives of minimising the response and the idle time. The MCIER is designed to consider the factors of (a) time of day and (b) day of week on which the incident occurs. Also, the delays in the process of ambulance preparation, collecting casualties from incident sites and dropping-off casualties at hospitals are considered. The effectiveness of the time and day of occurrence of the incidents on the response time during MCIs is assessed by simulating the ambulance response to a hypothetical case study.

Contribution of this paper

In this paper, an approach has been developed, incorporating a NSA, to solve the problem of coordinating the response of ambulances in multiple MCIs. The co-ordination problem of the emergency response to multiple MCIs includes the allocation of ambulances to casualties and, subsequently, the allocation of casualties to hospitals. In the NSA, a number of structures have been developed to achieve the objectives of minimising (i) the overall response time to deliver all casualties to hospitals and (ii) the maximum idle time of all ambulances. In addition to the NSA, the approach includes a realistic representation of the road network in the problem environment under consideration, which provides a level of detail needed to generate ambulance travel times based on accurate distances of the routes to be used.

PROBLEM DEFINITION

The emergency response co-ordination problem consists of a number of casualties n_c, where $c_i \in C$ and $1 \leq \mathrm{i} \leq n_c$ located at a number of incident sites n_{is}, where $is_i \in IS$ and $1 \leq \mathrm{i} \leq n_{is}$. Further, each casualty needs to be transferred from an incident site to a hospital $h_i \in H$, where there are n_h hospitals and $1 \leq \mathrm{i} \leq n_h$, by an ambulance $a_i \in A$, where there are n_a ambulances and $1 \leq \mathrm{i} \leq n_a$. Also, ambulances are initially located at one

of n_{as} ambulance stations $as_i \in AS$ where $1 \leq i \leq n_{as}$. Each hospital has unlimited capacity and can accept any casualty, each of which has equal priority. In addition, all ambulances are considered to be the same and all are able to transport one casualty per trip to hospital. The speed of ambulances is modelled as depending on day of the week and time of day as indicated in (McCormack & Coates, 2015). Table 1 summarises the elements and parameters involved in the co-ordination problem. The solution to this problem has the objectives of minimising: (i) the overall response time, which represents the time to deliver the last casualty to hospital; (ii) the maximum idle time of all ambulances, which is the maximum time that an ambulance spends in an idle state. Thus, a solution method must make a number of allocation decisions including (a) which ambulance from which ambulance station to allocate to which incident site?, (b) which casualty will be allocated to which ambulance?, (c) which hospital should an ambulance carrying a casualty be allocated?

Elements	Definition
$\boldsymbol{C}$	Set of casualties
$\boldsymbol{IS}$	Set of incident sites
$\boldsymbol{H}$	Set of hospitals
$\boldsymbol{A}$	Set of ambulances
$\boldsymbol{AS}$	Set of ambulance stations
Parameters	
$\boldsymbol{n_c}$	Number of casualties
$\boldsymbol{n_{is}}$	Number of incident sites
$\boldsymbol{n_h}$	Number of hospitals
$\boldsymbol{n_a}$	Number of ambulances
$\boldsymbol{n_{as}}$	Number of ambulance stations
$\boldsymbol{S_d^{(t)}}$	Ambulance speed based on the day of week *d* and time of day *t*
$\boldsymbol{T_b}$	The time between receiving the initial emergency call to attend an incident site and an ambulance departing from the ambulance station
$\boldsymbol{T_d}$	On arrival at hospital, the time taken for an ambulance crew to drop-off a casualty before departing to collect another casualty
$\boldsymbol{T_c}$	On arrival at an incident site, the time taken for an ambulance crew to collect a casualty from the incident site and depart for hospital

Table 1. Problem elements and parameters

MODEL

The model of co-ordinating the emergency response to MCIs includes a problem environment being defined which includes a MCI scenario and a road network. Subsequently, a solution method is applied to the problem environment in order to create a response plan; please see Figure 1.

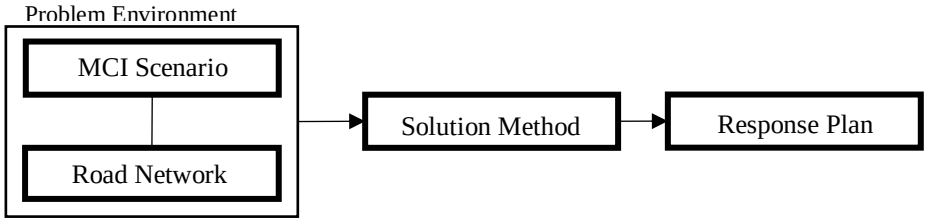


Figure 1. Overview of the MCIER approach

MCI scenario and road network

The problem environment requires a number of defined parameters to initialise the MCI scenario including the number and location of C, IS, H, A, and AS. A road network of the geographical area of interest is constructed using Ordnance Survey MasterMap (OSM) (Survey, 2019). It is one of the available sources of highly-detailed geographic data of Great Britain. The road network is represented as an undirected weighted graph $G = [V, E]$, where V is a set of vertices and E is a set of edges. Roads are represented by edges where each road has a type and a length. The start and end of each road are represented by vertices. The locations of ambulance stations and hospitals are established by converting their actual postcodes to the northing and easting coordinates using Grid

reference (Gridfinder, 2011). Then, these are assigned to the nearest vertex in the road network. Further, incident sites are located at vertices.

Objective functions

In order to evaluate a solution, two objectives are used, $f_1(s)$ is the overall response time that represents the time taken to deliver the last casualty to hospital and $f_2(s)$ is the maximum idle time of all ambulances. The optimization problem is to find an allocation of tasks to ambulances, which first minimises $f_1(s)$ and second minimises $f_2(s)$, i.e.

$$f_1(s) = \max_{i,j} \sum_{k=1}^{n_t} TD_{k,i,j} \qquad f_2(s) = \max_{i,j} IT_{i,j}$$

where i and j indicate the i^{th} ambulance originally located at the j^{th} ambulance station respectively. Further, k represents the k^{th} task allocated to an ambulance, where n_t is the number of tasks. Also, the duration of each task, $TD_{k,i,j}$, assigned to an ambulance must be established. For example, the time taken to transport a casualty from an incident site to a hospital can be established using knowledge of the route to be taken in terms of distance and the speed of the ambulance based on day of week and time of day.

Solution method and response plan

Pseudo-code for the developed Neighbourhood Search Algorithm (NSA) is presented in Algorithm 1. The NSA produces a new response plan at each iteration. However, the previous plan will be kept unless an improvement is made in the new plan. At each iteration, an attempt is made to find an improved plan by selecting and applying one of five neighbourhood structures each of which makes changes to the current plan. The neighbourhood structures include (a) allocate a casualty to a different hospital (CH), (b) swap two casualties between two different ambulances (SCDA), (c) swap the position of two casualties in the same ambulance (SCSA), (d) move a casualty from one ambulance to another (MC), (e) assign a casualty from the ambulance that has the highest workload to the one that has the lowest workload (BW); please refer to Figure 2 for details. In relation to (e), this structure was inspired by the work presented in (Amiri *et al.*, 2010).

An initial solution is generated by allocating a number of tasks to each ambulance. These tasks are (a) travel to the incident site, (b) collect the assigned casualty, and (c) transfer the casualty to the assigned hospital. It is important to consider the possible delays that may occur during the response process which will affect the response time. Delays related to (a) the preparation time, (b) the collection time, and (c) the dropping-off time are considered. Figure 3 presents an example of how tasks are allocated to a single ambulance including the delays associated with each task. There is no prior knowledge, or assumption, of the duration of each task which depends on from where the casualty is collected and to which hospital the casualty is delivered. In relation to travelling to/from an incident site, and to/from a hospital, Dijkstra's algorithm is employed to find the shortest path between two locations. The effectiveness of the day and time on the response time for the same path has been investigated and is presented later in this paper.

Algorithm 1. NSA

1.	$\boldsymbol{plan} \leftarrow$ **INITIALIZE**()	Initialise response plan (*plan*)
2.	Calculate $\boldsymbol{time}$ for $\boldsymbol{plan}$	
3.	Define a set of neighbourhood structures $\boldsymbol{N_s}$	$N_s = \{N_0, \ldots\ldots, N_n\}\ where\ n = 4$
4.	$\boldsymbol{i} \leftarrow \boldsymbol{0}$	Set the termination condition
5.	**While** $\boldsymbol{i} \leq \boldsymbol{n-1}$ **do**	
6.	$\boldsymbol{copyPlan} \leftarrow \boldsymbol{Plan}$	Preserve the original plan
7.	$\boldsymbol{rand} \leftarrow$ **RND**()	$rand\ (0,4)$
8.	$\boldsymbol{op} \leftarrow$ **SELECT**($\boldsymbol{rand}$)	Select structure $op \in N_s$
9.	Apply the selected structure $\boldsymbol{op}$ and generate $\boldsymbol{plan'}$	Create next $plan$
10.	Calculate $\boldsymbol{time'}$ for $\boldsymbol{plan'}$	
11.	**if** $\boldsymbol{time'} < \boldsymbol{time}$ **then**	
12.	$\boldsymbol{plan} \leftarrow \boldsymbol{plan'}$	
13.	Remove $\boldsymbol{copyPlan}$	
14.	**else**	
15.	$\boldsymbol{Plan} \leftarrow \boldsymbol{copyPlan}$	Retrieve the original plan
16.	$\boldsymbol{i}$++	
17.	**end if**	
18.	**end while**	
19.	Issue the final $\boldsymbol{plan}$	

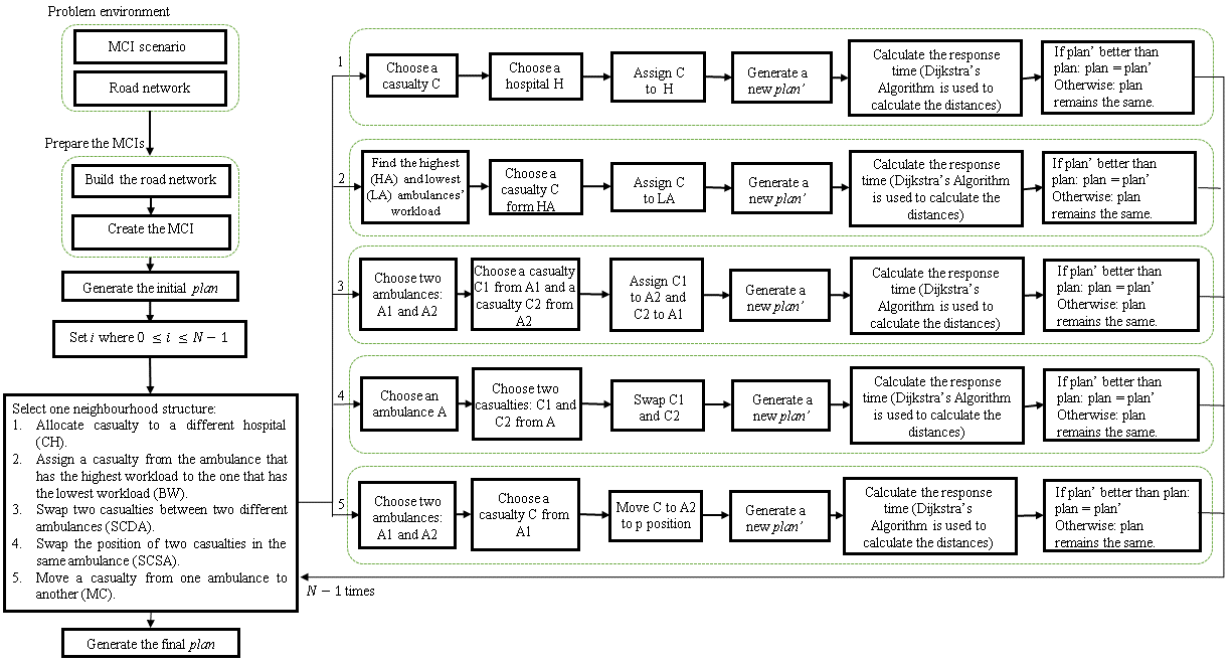


Figure 2. Details of The MCIER approach

Figure 3. An example of the tasks allocated to a single ambulance

Validation

For validation purposes in terms of determining the best response plan, for a simple MCI problem, both an exact method, i.e. a Greedy Algorithm (GA), and the NSA were used. The simple MCI problem considered consisted of 12 ambulances initially distributed between 3 ambulance stations, 35 casualties distributed between 2 incident sites, with each casualty needing to be transported to one of 3 hospitals; please see Figure 4. The distances between locations are indicated in Table 2. The response time obtained by both the GA and NSA were the same, i.e. one hour and 32 minutes.

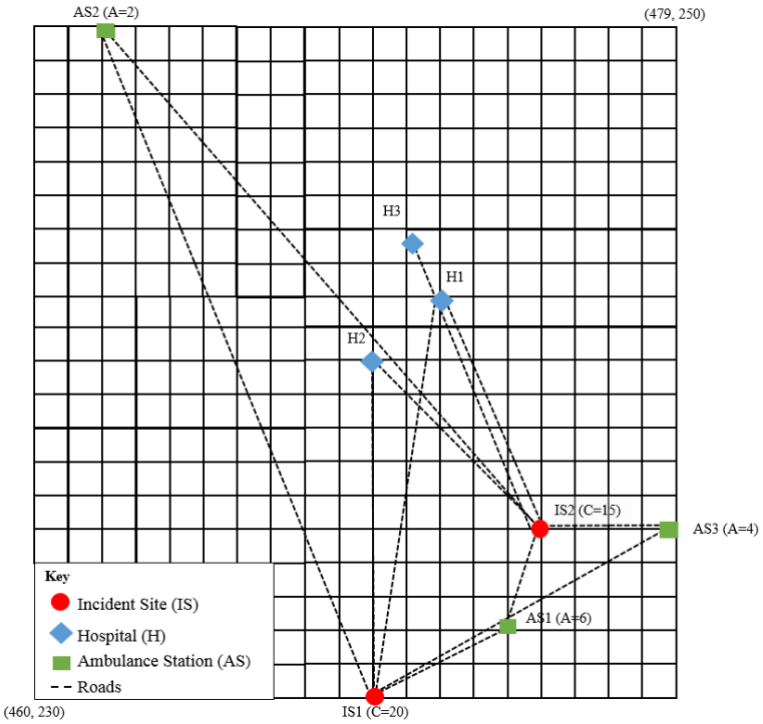


Figure 4. A Grid representation of a simple MCI problem

In this research, a NSA has been designed and used since the co-ordination problem will be further developed to include multiple dimensions such that an exact method will not be applicable (Hu et al., 2005). In addition, it is acknowledged that the execution of an exact method may be time-consuming whereas the NSA developed will not, which is critical in emergency response situations.

Another validation has been carried out for the road network using a route planner and Dijkstra's algorithm to ensure that the calculated distance between two locations is reasonable. A number of vertices have been selected on the map of the area of interest, which will be discussed later in this paper, and the distance between every two locations was calculated and compared. It is noticed that the path that was generated using Dijkstra's algorithm passes through buses and taxis lane which is not allowed in the AA route planner as it is created for normal vehicles. Further, ambulance vehicles are allowed to use some of the roads in an unintended direction if this would reduce the response time. However, this is not allowed for normal vehicles. Therefore, these reasons might cause minor differences in the total distance.

	IS1	**IS2**
AS1	4.47 km	3.16 km
AS2	21.54 km	19.95 km
AS3	10.30 km	4.0 km
H1	12.17 km	7.62 km
H2	10 km	7.1 km
H3	14.04 km	9.85 km

Table 1. The distance table for the simple MCI problem

CASE STUDY OF A HYPOTHETICAL MCI

Overview

Two incidents were assumed to occur on Sunday at 16:00 in the city of Newcastle-upon-Tyne in the North-East of England; Newcastle City Centre (NCC) and Byker Metro Station (BMS). These locations have been selected as such locations are densely populated and present major challenges for the emergency services in dealing with

MCIs (The UK Cabinet Office, 2017). Also, as indicated in Table 2, the environment consists of 2 hospitals including the Royal Victoria Infirmary (RVI) and Freeman Hospital (FH); 2 ambulance stations including St John Ambulance Station (SJA) and Sandyford Road Ambulance Station (SRA); 8 ambulance vehicles are located at SJA, and 7 ambulance vehicles are located at SRA. It is assumed that all ambulances are available when the incidents occur. The average speed of the ambulances during the time of the incident occurrences is assumed to be 23 km/h based on the average ambulance vehicle speed data presented in (McCormack & Coates, 2015). Figure 5 shows a representation of the road network of the city of Newcastle-upon-Tyne in which all locations of interest are labelled. The road network shown in Figure 5 consists of 7413 vertices and 9962 edges. The range of edge lengths is from 1.1 meters to 1145.4 meters. Only 9.1% of the edges are longer than 150 meters. The easting and northing of the top right coordinate of the map are (428014, 567866) and the bottom left coordinate are (422109, 563146) respectively. This case study aims to assess the co-ordination of the response to a multiple site MCI such that the response time is minimised, which is the time of delivering the last casualty from NCC and BMS to the RVI or FH. Also, the maximum idle time of all ambulances is minimised. The busy time, which is the duration of carrying out all the allocated tasks of each ambulance, and the idle time of each ambulance are recorded during the simulation.

Ambulance Stations		**No. Ambulance vehicles**	**(Easting, Northing)**
SJA	St John Ambulance Station	8	(422655, 564475)
SRA	Sandyford Road Ambulance Station	7	(425399, 565102)
Hospitals			
RVI	Royal Victoria Infirmary		(424457, 565003)
FH	Freeman Hospital		(426116, 567650)

Table 2. Hospitals and resources available at ambulance stations

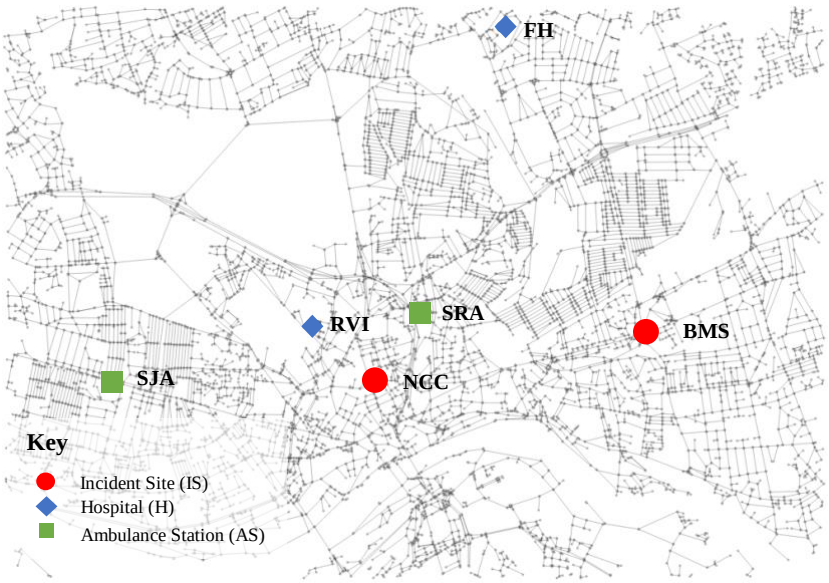


Figure 5. The road network map generated

Definition of scenario 1 and scenario 2

Both scenarios contain 35 casualties distributed between two incident sites (i.e. NCC and BMS) each of which has a different casualty distribution. In scenario 1, there are 25 casualties located at the NCC site and 10 casualties located at the BMS site. In contrast, scenario 2 involves 25 and 10 casualties located at the BMS site and the NCC site respectively. These two scenarios, with varying casualty distribution, were selected in order to find out to which hospitals the casualties will be delivered when the choice of hospital may not be intuitive.

PRELIMINARY RESULTS AND DISCUSSION

The algorithm was applied a hundred times, each time with 5000 iterations. The case study with two scenarios have been assumed each of which has a different casualty distribution; see Table 3 and Table 4. For both scenarios, the best four unique plans were selected and discussed. The NSA structures were evaluated in order to find their effectiveness on the response plan.

The response plans of the MCI scenario

Result for scenario 1

Table 3 presents the best four plans ($P1 - P4$) that all of which are unique and their corresponding response time. In all plans, the casualties located at the NCC site are all 25 transferred to the nearest hospital i.e. the RVI.

Plans	NCC (25)		BMS (10)		Response time (mins)	Total of casualties	
	RVI	FH	RVI	FH		RVI	FH
P1	25	0	5	5	47.5	30	5
P2	25	0	6	4	47.5	31	4
P3	25	0	7	3	47.5	32	3
P4	25	0	8	2	47.5	33	2

Table 3. A number of possible response plans ($P1 - P4$)

Result for scenario 2

The best four plans ($P5 - P8$), along with their corresponding response time, were recorded. Table 4 presents these four plans all of which are unique. In all plans, most casualties located at both incidents are transferred to the closest hospital, i.e. the RVI, where only a few of the casualties at both incident sites are transferred to the FH.

	NCC (10)		BMS (25)		Response time (mins)	Total of casualties	
	RVI	FH	RVI	FH		RVI	FH
P5	10	0	22	3	70.6	32	3
P6	9	1	21	4	70.6	30	5
P7	9	1	18	7	70.6	27	8
P8	8	2	18	7	70.6	26	9

Table 4. A number of possible response plans ($P5 - P8$)

In contrast to all four plans (P1 to P4) for scenario 1 in which all 25 casualties located at the NCC incident site were transferred to the RVI hospital, plans 6 to 8 in scenario 2 indicate that most casualties should be transferred from the NCC incident site to the RVI and one or two to the FH. Specifically, plans 6 and 7 have 9 casualties assigned to the RVI and 1 to the FH, whereas plan P8 has 8 casualties assigned to the RVI and 2 to the FH. In scenario 2, the reason why all casualties are not taken to the nearest hospital (RVI) is that doing so does not reduce the overall response time, i.e. the time to deliver the last casualty to hospital. That is, the ambulances to which these casualties are assigned do not lie on the critical path in terms of the overall response time.

The evaluation of the NSA structures

The NSA structures were evaluated to find the effectiveness of all structures in combination on the response time of the four plans generated for scenario 1 ($P1 - P4$) referred to in Table 6. It is noticed that the BW structure has a major effect on the response time as it made a number of improvements in all plans. It is noted that the SCDA, SCSA and MC structures will not change the overall response if (i) all casualties are the same and (ii) the casualties selected to be swapped are located at the same incident site and are assigned to the same hospital. However, since the casualties selected to be swapped may be located at different incident sites or allocated to different hospitals, then the overall response time will be affected (i.e. increased or decreased). For example, consider applying SCDA for two particular ambulances. A swap may decrease the overall response time if the next casualty allocated to an ambulance is located at the nearest of the multiple incident sites to the hospital at which it has just delivered a

casualty. Conversely, this swap may increase the overall response time if the next casualty allocated to the ambulance is located at the furthest of the multiple incident sites to the hospital at which it has just delivered a casualty. Indeed, the same argument applies to the casualty allocated to an ambulance immediately prior to a swap being applied.

Plans	CH	BW	SCDA	SCSA	MC	Total no. of improvements	No. of iterations to reach the best plan
P1	3	25	1	0	1	30	1519
P2	0	38	1	1	2	42	1472
P3	**3**	**28**	**3**	**0**	**2**	**36**	**1372**
P4	0	25	2	2	5	34	1589

Table 5. The effectiveness of the NSA structures on the response time of plans ($P1 - P4$)

Further, the number of iteration of reaching the best response time for these plans is considered in the last column in Table 5. It is noticed that the best response time has been reached faster in plan P3 which is in the iteration 1372. In order to find the optimum plan between the proposed plans ($P1 - P4$) in terms of idleness, the maximum idle time is recorded for all plans. Table 6 shows that the best plan of the four is P4 where the response to the MCIs is completed with the lowest idle time. Figure 6 illustrates the response plan of P4 including the delays in between tasks.

Plans	Idle Time (mins)	%
P1	8.00	16.8
P2	8.00	16.8
P3	8.00	16.8
P4	**6.00**	**12.6**

Table 6. The maximum idle time of plans ($P1 - P4$)

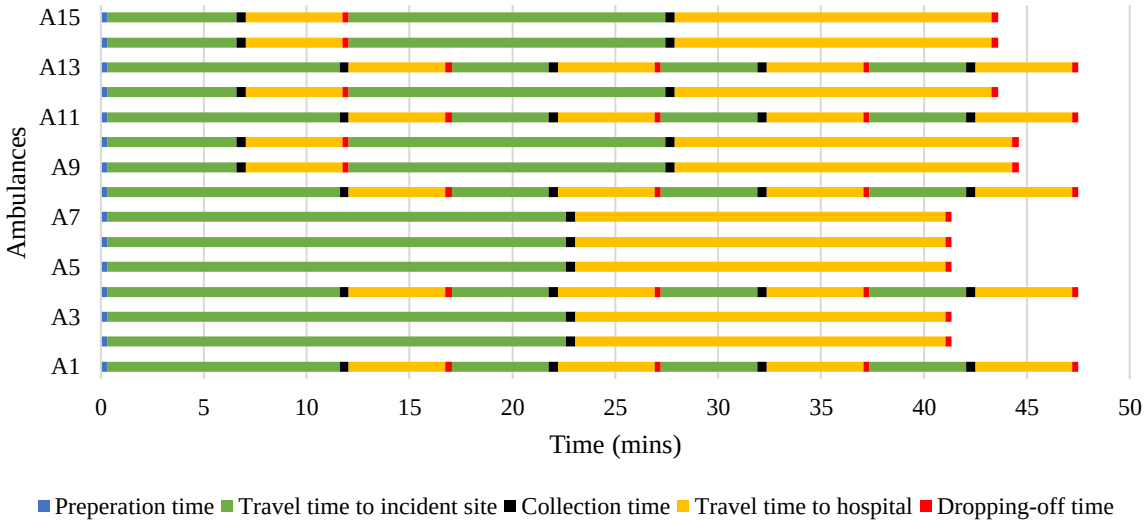


Figure 6. A Gantt chart of the response plan of scenario 1- $P4$

The effectiveness of the day and time on the response plan

The impact of the time of day and day of week on the response time has been investigated in scenario 1-$P4$. Different level of a traffic congestion have been considered based on the road traffic in a certain time of day. There are modelled by changing the speed of the ambulances where ambulance speed data is derived from the work presented in (McCormack & Coates, 2015). Figure 7 shows the differences in the response time when considering the same MCI scenario 1 but vary ambulance speed depending on different days and times. From

Monday to Friday between 5:00 and 16:00 the response times increase and fluctuate over the day based on the traffic congestion. However, on the weekend, the response times increase from 7:00 to 14:00 on Saturday and from 7:00 to 12:00 on Sunday. The response time reaches its minimum on most days at 5:00. The variation in the response time during the time of day and the day of week leads to the necessity of considering these variations when simulating the response to MCIs.

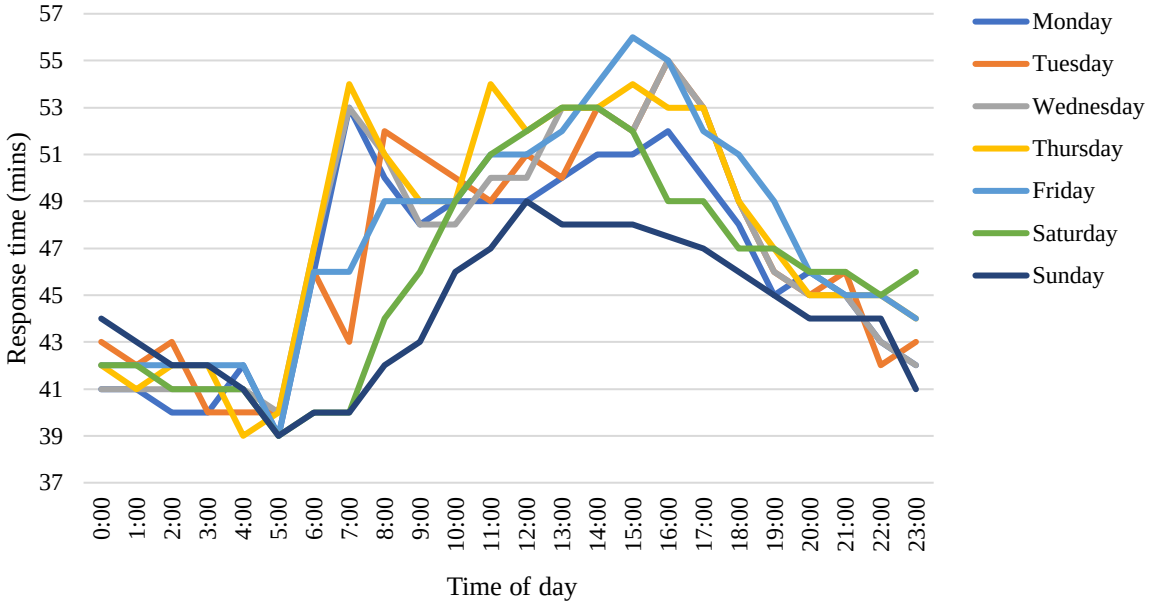


Figure 7. The response times of scenario 1- *P*4 considering ambulance speed on different days and times

CONCLUSION AND FUTURE WORK

MCIs can result in different numbers and conditions of casualties, numbers of fatalities, and thus the medical needs and the response plans required can be different. The shortage of resources, i.e. ambulances, could affect the response operation. Thus, decisions should be taken in a coordinated manner. Co-ordination involves resource allocation (i.e. deciding which ambulance should be assigned to which incident), task allocation (i.e. which casualty is assigned to which ambulance and which hospital should a casualty be assigned to); all of these are crucial in order to distribute the resource among the casualties and avoid tasks overlapping.

In this paper, a NSA has been developed and used to produce the best possible plan for the proposed case study. The case study involved multi-incidents and was proposed to occur in Newcastle-upon-Tyne on a specific day and time, i.e. Sunday at 16:00. A number of experiments were carried out with varying casualty distributions between incidents. The objectives of the MCIER have been set to minimising the overall response time and, then, minimising the maximum idle time of all ambulances. An investigation has been made to find how the time of day and day of week affect the response time. The results show the necessity of considering the time and day of the incident occurrence when developing any MCI decision support system. There is more work to be done in the area of MCIs regarding modifying the current approach to be dynamic in nature. This will involve receiving and updating real-time information from the environment to improve the current response. Further, consideration must be given to the occurrence of new incidents during the operation as several MCIs could occur while the response to other incidents is ongoing. Finally, the capacity and treatment specialism of receiving hospitals, and the capacity of ambulances along with the dynamic nature of casualties' health state will be considered.

REFERENCES

Hu, J., Li, B., & Kihara, D. (2005) Limitations and potentials of current motif discovery algorithms *Nucleic Acids Research*, **33**, 4899–4913. doi:10.1093/nar/gki791

Amiri, M., Zandieh, M., Yazdani, M., & Bagheri, A. (2010) A variable neighbourhood search algorithm for the flexible job-shop scheduling problem *International Journal of Production Research*, **48**, 5671–5689. doi:10.1080/00207540903055743org/10.1080/00207540903055743

Amram, O., Schuurman, N., Hedley, N., & Hameed, S. M. (2012) A web-based model to support patient-to-hospital allocation in mass casualty incidents *Journal of Trauma and Acute Care Surgery*, **72**, 1323–1328.

doi:10.1097/TA.0b013e318246e879

Budge, S., Ingolfsson, A., & Zerom, D. (2010) Empirical Analysis of Ambulance Travel Times: The Case of Calgary Emergency Medical Services *Management Science*, **56**, 716–723. doi:10.1287/mnsc.1090.1142

Centre of Trauma Sciences (2016) *Pan London Major Trauma Networks: Response to Mass Casualty Incident*. London. Retrieved from http://www.c4ts.qmul.ac.uk/downloads/network-dox/lts-mass-casualty-response.pdf

Chen, R., Sharman, R., Rao, H. R., & Upadhyaya, S. J. (2008) Coordination in emergency response management *Communications of the ACM*, **51**, 66–73. doi:10.1145/1342327.1342340

Department of Health (2007) Mass Casualties Incidents – A Framework for Planning, 1–29. Retrieved from http://webarchive.nationalarchives.gov.uk/20130124035118/http:/www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_073397.pdf

Dijkstra, E. W. (1959) A note on two problems in connexion with graphs *Numerische Mathematik*, **1**, 269–271. doi:10.1007/BF01386390

Frykberg, E. R. (2002) Medical Management of Disasters and Mass Casualties From Terrorist Bombings: How Can We Cope? *The Journal of Trauma: Injury, Infection, and Critical Care*, **53**, 201–212. doi:10.1097/00005373-200208000-00001

Gong, Q. & Batta, R. (2007) Allocation and reallocation of ambulances to casualty clusters in a disaster relief operation *IIE Transactions (Institute of Industrial Engineers)*, **39**, 27–39. doi:10.1080/07408170600743938

Gridfinder (2011) Grid Reference Finder. Retrieved 1 August 2018, from https://gridreferencefinder.com/

Hawe, G. I., Coates, G., Wilson, D. T., & Crouch, R. S. (2015) Agent-based simulation of emergency response to plan the allocation of resources for a hypothetical two-site major incident *Engineering Applications of Artificial Intelligence*, **46**, 336–345. doi:10.1016/j.engappai.2015.06.023

Jotshi, A., Gong, Q., & Batta, R. (2009) Dispatching and routing of emergency vehicles in disaster mitigation using data fusion *Socio-Economic Planning Sciences*, **43**, 1–24. doi:10.1016/J.SEPS.2008.02.005

Kamali, B., Bish, D., & Glick, R. (2017) Optimal service order for mass-casualty incident response *European Journal of Operational Research*, **261**, 355–367. doi:10.1016/j.ejor.2017.01.047

Kolesar, P., Walker, W., & Hausner, J. (1975) Determining the Relation between Fire Engine Travel Times and Travel Distances in New York City *Operations Research*, **23**, 614–627. doi:10.1287/opre.23.4.614

Lerner, E. B., Schwartz, R. B., Coule, P. L., … O'Connor, R. E. (2008) Mass Casualty Triage: An Evaluation of the Data and Development of a Proposed National Guideline *Disaster Medicine and Public Health Preparedness*, **2**, S25–S34. doi:10.1097/DMP.0b013e318182194e

London Assembly (2006) Report of the 7 July Review Committee *Greater London Authority*, 157. Retrieved from http://news.bbc.co.uk/1/shared/bsp/hi/pdfs/05_06_06_london_bombing.pdf

Lowes, A. & Cosgrove, J. (2016) Prehospital organization and management of a mass casualty incident *BJA Education*, **16**, 323–328. doi:10.1093/bjaed/mkw005

Mackway-Jones, K. & Wiley, J. (2012) *Major Incident Medical Management and Support: The Practical Approach at the Scene* Third Edit. Wiley-Blackwell. Retrieved from http://healthindisasters.com/images/Books/Major-Incident-Medical-Management-and-Support-Third-Edition.pdf

Malone, T. W. & Crowston, K. (1994) The Interdisciplinary Study of Coordination *ACM Computing Surveys*, **26**. Retrieved from http://docenti.unicam.it/tmp/3687.pdf

McCormack, R. & Coates, G. (2015) A simulation model to enable the optimization of ambulance fleet allocation and base station location for increased patient survival *European Journal of Operational Research*, **247**, 294–309. doi:10.1016/j.ejor.2015.05.040

Mete, H. O. & Zabinsky, Z. B. (2010) Stochastic optimization of medical supply location and distribution in disaster management *International Journal of Production Economics*, **126**, 76–84. doi:10.1016/J.IJPE.2009.10.004

Muaafa, M., Concho, A. L., & Ramirez-Marquez, J. (2014) Emergency Resource Allocation for Disaster Response: An Evolutionary Approach *SSRN Electronic Journal*, 1–10. doi:10.2139/ssrn.2848892

NHS England National Emergency Preparedness Resilience and Response Unit (2015) *NHS England Emergency Preparedness, Resilience and Response Framework*. Retrieved from https://www.england.nhs.uk/wp-content/uploads/2015/11/eprr-framework.pdf

Pereira, A. H., Nardin, L. G., Brandão, A. A. F., & Sichman, J. S. (2011) LTI Agent Rescue Team: A BDI-based Approach for Robocup Rescue *Proceedings of the RoboCup 2011*. Retrieved from https://www.researchgate.net/profile/Luis_Nardin2/publication/235346574_LTI_Agent_Rescue_Team_A_BDI-based_Approach_for_Robocup_Rescue/links/02bfe511237be81faf000000/LTI-Agent-Rescue-Team-A-BDI-based-Approach-for-Robocup-Rescue.pdf

Repoussis, P. P., Paraskevopoulos, D. C., Vazacopoulos, A., & Hupert, N. (2016) Optimizing emergency preparedness and resource utilization in mass-casualty incidents *European Journal of Operational Research*, **255**, 531–544. doi:10.1016/J.EJOR.2016.05.047

Schmid, V. & Doerner, K. F. (2010) Ambulance location and relocation problems with time-dependent travel times *European Journal of Operational Research*, **207**, 1293–1303. doi:10.1016/J.EJOR.2010.06.033

Survey, O. (n.d.) *OS MasterMap Integrated Transport Network Layer user guide and technical specification - 30UG*. Retrieved from https://digimap.edina.ac.uk/webhelp/os/data_files/os_manuals/osmm_itn_userguide_v1.0.pdf

The UK Cabinet Office (2017) *National Risk Register of Civil Emergencies National Risk Register of Civil Emergencies*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/644968/UK_National_Risk_Register_2017.pdf

Wex, F., Schryen, G., & Neumann, D. (2012) *A Fuzzy Optimization Model for Scheduling and Allocating Operational Emergency Response under Informational Uncertainty: A Fuzzy Optimization Model for Scheduling and Allocating Rescue Units Canada*. Retrieved from https://epub.uni-regensburg.de/23331/1/ISCRAM_2012_-_Proceedings_version.pdf

Wilson, D. T., Hawe, G. I., Coates, G., & Crouch, R. S. (2013) A multi-objective combinatorial model of casualty processing in major incident response *European Journal of Operational Research*. doi:10.1016/j.ejor.2013.04.040

Yi, W. & Kumar, A. (2007) Ant colony optimization for disaster relief operations *Transportation Research Part E: Logistics and Transportation Review*, **43**, 660–672. doi:10.1016/j.tre.2006.05.004

Zhang, J.-H., Li, J., & Liu, Z.-P. (2012) Multiple-resource and multiple-depot emergency response problem considering secondary disasters *Expert Systems with Applications*, **39**, 11066–11071. doi:10.1016/J.ESWA.2012.03.016

A New Data-Driven Approach to Measuring Hurricane Risk

Duygu Pamukçu
Virginia Tech
duygu@vt.edu

Christopher W. Zobel
Virginia Tech
czobel@vt.edu

Andrew Arnette
University of Wyoming
aarnette@uwyo.edu

ABSTRACT

Improving disaster operations requires understanding and managing risk. This paper proposes a new data-driven approach for measuring the risk associated with a natural hazard, in support of developing more effective approaches for managing disaster operations. The paper focuses, in particular, on the issue of defining the inherent severity of a hazard event, independent of its impacts on human society, and concentrates on hurricanes as a specific type of natural hazard. After proposing a preliminary severity measure in the context of a hurricane, the paper discusses the issues associated with collecting empirical data to support its implementation. The approach is then illustrated by comparing the relative risk associated with two different locations in the state of North Carolina subject to the impacts of Hurricane Florence in 2018.

Keywords

Risk, Severity, Natural hazard, Analytic methods

INTRODUCTION

Disasters are catastrophic events that often cause many causalities and require the mobilization of significant numbers of resources to protect against their impacts (de Boer, 1990). Due to the increasing population of the world, and the increasing vulnerability of that population, these impacts are growing and require urgent attention. Rodriguez et al. (2011) argue that the political, economic and social considerations of global society force organizations to find more efficient ways of managing these destructive events. Assessing the characteristics of the events, and their possible destructive effects, is particularly important in the context of humanitarian relief operations, since they can have a significant impact on the ability to provide relief to those who need it in the wake of a disaster.

Resource allocation is a challenging problem in disaster management. Organizations spend their time and effort to find efficient ways of pre-positioning and distributing resources in order to provide better service to affected communities. Access to timely and appropriate information can play an important role in clarifying the situation and making appropriate decisions. Organizations should thus be aware of potential data sources to support such decision making. With this in mind, this study discusses a data-driven approach for quantifying disaster risk in terms of community characteristics and the inherent severity of a hazard event. We have a motivation of assessing the county-based risk of the hazard event to help organizations with their decision making, especially in efficient asset placement, in disaster management.

BACKGROUND

The social science literature includes many studies on measuring relative risk based on the likelihood of a hazard and the characteristics of the impacted community (Aerts et al., 2013, Willis et al., 2006). Arnette and Zobel (2019) adopt such an approach for quantifying risk as part of their model to optimize the placement of assets to support opening disaster shelters. Specifically, they use a common measure of risk that is a function of the probability of the occurrence of a hazard, H, the extent to which the population is exposed to that hazard, E, and the social vulnerability of the population (independent of any particular hazard), V:

$$R = H * E * V \quad (1)$$

By then letting H_{ij} represent the likelihood that a hazard of type j will occur in location i, where E_{ij} represents the corresponding level of exposure of the population in that location and V_i represents the corresponding vulnerability, Arnette and Zobel (2019) are able to calculate the total combined risk associated with multiple potential hazards in location i as follows:

$$R_i = (\sum_{j=1}^{n}(H_{ij}E_{ij}))V_i \quad (2)$$

What is missing from this measure, however, is an explicit representation of the *severity* of these potential hazard events, independent of their impacts on the given location. This is important, since one would expect a more severe event to have a larger destructive impact on a given location than would a less severe event. This implies that if one were able to capture the relative severity of the hazard itself, then the varying levels of risk that a location is subject to under different circumstances could be characterized more effectively. This current study is a first step towards being able to explicitly incorporate a measure of exogenous severity into such an analysis.

Although the severity of hazard events is widely studied in the literature, the treatment of the concept varies depending on the type of study and its objectives. For example, Rodriguez et al. (2011) propose a decision support methodology to assist NGOs with the assessment of the consequences of disasters and provide a comparative analysis of different statistical learning techniques. The authors use a scenario-based approach to assess the severity of disaster in terms of its impacts by considering such factors as casualties, injured and homeless people, infrastructure damage, etc. De Boer (1990), in turn, combines the causes and the effects of a disaster to create a Disaster Severity Scale which includes a variety of attributes such as the effect on the surrounding community, the cause, the duration of that cause, the radius of the disaster area, and the time required by rescue teams for initial treatment. Alternatively, the study of de Boer et al. (1989) defines a Medical Severity Index of Disaster to support decision making in medical care supply chain operations in disaster situations. This index quantifies the severity of the incident by considering the level of injury and the requirement for treatment, along with other factors like disaster type, population, and location. Zhang and Huang (2018) also assign a severity value to all types of disasters, based on the number of deaths that occur, noting that droughts, extreme temperatures and earthquakes have the highest severity values and storms have lower severity but higher uncertainty.

The common thread among each of these research efforts is the assessment of severity by using measures that reflect the actual impacts on a population of a disaster event that is caused by a natural hazard. In contrast to this, our effort instead considers the inherent severity of the hazard itself, rather than that of the disaster, which should be measurable even in the absence of human impact. This is important because if one ultimately wishes to compare different communities' ability to resist the effects of a disaster, then it can be important to know the actual severity of the hazard itself, independent of its complex interaction with the communities. This would allow for more effectively comparing the relative contributions of different characteristics of the communities and their populations towards their ability to resist against and recover from a disaster.

MEASURING SEVERITY

In particular, our focus in this paper is on developing the capability to characterize the exogenous severity of a particular type of hazard event, a hurricane, in specific locations. Although the well-known Saffir-Simpson scale is frequently used to characterize the severity of an entire hurricane, based on the storm's maximum wind speed (NHC, 2018), different locations that are impacted by that same hurricane may experience very different conditions and thus not be subject to the same level of severity. Chouinard et al. (1997) discuss this general tendency to describe the severity of a hurricane as a function of the wind speed only, despite the presence of other potential measures of severity such as pressure deficit and maximum significant wave height. Aerts et al. (2013) also argue that not just high winds but also heavy rainfall and flooding due to storm surge are the main source of the destructive impacts of hurricanes. In addition, Schembri (2018) explicitly states that the main issue with Hurricane Florence, in particular, was rainfall rather than wind speed. Given these assessments, and the motivation for developing a localized measure of severity that can be related to risk in a specific location, as in equation (2) above, we focus on localized measurements such as rainfall, wind speed, wind direction, and flood warnings as potential indicators of hurricane severity.

This use of multiple indicators to represent the different aspects of the severity of a hurricane can easily be extended to the severity of other types of natural hazard such as that of an earthquake, which can be expressed in terms of magnitude, intensity, energy and acceleration (Gutenberg and Richter, 1942). In the long run, our hope is to define a generalizable approach for characterizing the core elements of severity that can be applied across different types of hazard. In this initial study, however, our focus is on hurricanes and on measuring their particular severity.

As a simple approach for measuring the localized severity, S, of a hurricane, we initially use a convex combination of a set of multiple indicator variables, *s*, each of which is normalized to maintain a consistent contribution:

$$S_i = \sum_{k=1}^{m} w_{ik} s_{ik} \quad (3)$$

In this case, *i* represents the specific location for which the hurricane's severity is being measured, *m* represents the total number of indicator variables chosen to be included in the measure, and *w* represents the weighted contribution of each indicator variable, as specified by the decision maker. Including weights in (3) allows for a decision maker to assign a greater relative importance to one or more of the indicator variables, and thus to prioritize the effects of wind over the effects of flooding, for example, under certain circumstances. Absent the motivation to make such a prioritization, however, we would expect each indicator variable to be weighted the same. Creating a single aggregated value for severity allows us to incorporate this severity measure into the measure of risk given in equation (2). In general, however, the set of indicators could be combined in some other way, or even conceptualized as a vector of different severity dimensions. In the context of this initial research effort, the straightforward formulation given in (3) simply allows us to establish how such a localized measure can be used to represent the complexity of the varying degrees of severity associated with a particular natural hazard.

EMPIRICAL DATA COLLECTION

We first explore the ability of a severity measure to characterize the local behavior of a hazard by applying our formulation of this measure to the analysis of a specific instance of a hurricane: Hurricane Florence, which struck the southeastern United States in September 2018. Florence was classified as a tropical storm on September 7th before strengthening to a major hurricane by September 10th and then weakening again to a Category 1 storm by the 13th of September. It made landfall near Wrightsville Beach, North Carolina on Friday, September 14th and then weakened further over the next few days as it moved inland and then northward. The following discussion details the process of collecting the empirical data upon which the analysis is based.

Weather data collection – We focused our data collection efforts for Hurricane Florence on the state of North Carolina. Historical weather data for each county in the state was retrieved from the National Oceanic and Atmospheric Administration (NOAA), using the *countyweather* package in R and including all data from September 7th to September 21st, 2018. The *countyweather* package, which requires an API key from NOAA, pulls all available weather data (both daily and hourly) from multiple weather stations. The core variables that it retrieves are temperature, wind speed, wind direction, and precipitation. Because the weather data is sparse for many counties during the specified date range, however, we ended up using only the daily average wind speed (in m/s) and the average precipitation (in mm).

In order to perform our preliminary analysis, we selected four specific counties with nearly complete data for the two variables of interest: these consisted of two adjacent counties from the coastal region (Carteret and Onslow) and two additional adjacent counties from the mountains (Buncombe and Henderson). Any missing data points in these counties were either estimated from hourly data, when available, or interpolated from the corresponding daily data (from the current day and the day before) in the adjacent county.

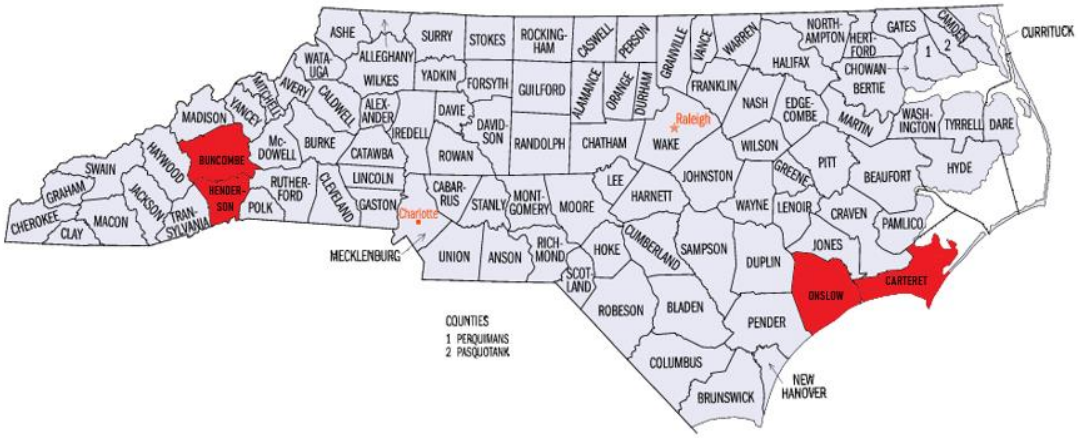


Figure 1. North Carolina State Map.
Source: https://commons.wikimedia.org/wiki/File:North_Carolina_counties.gif

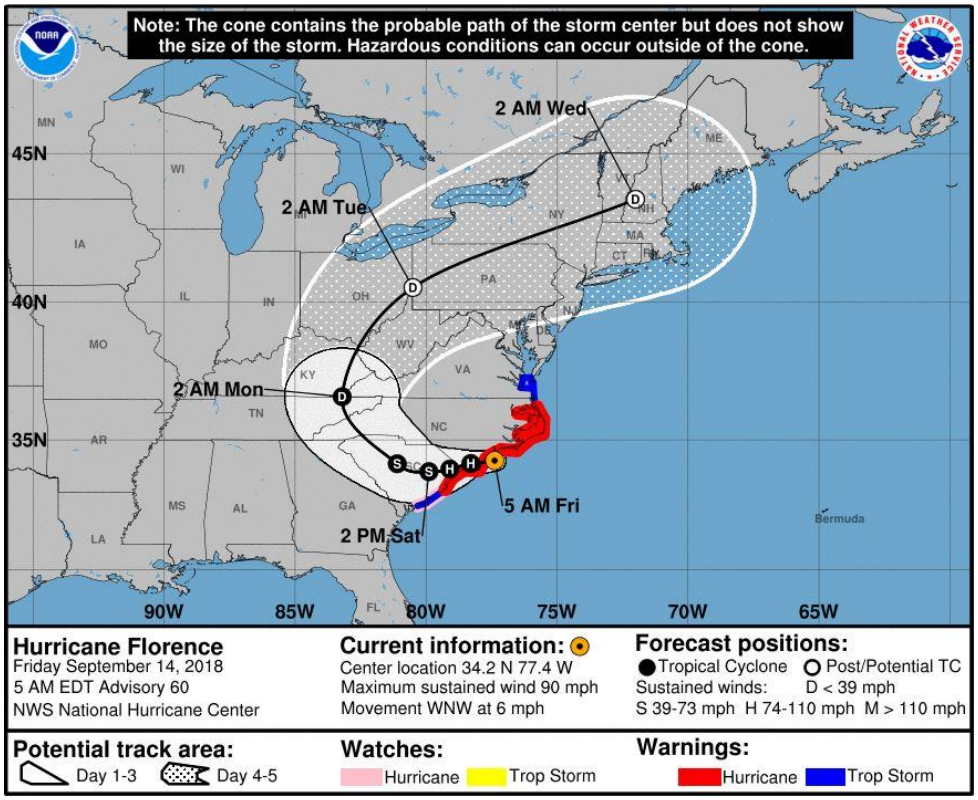


Figure 2. The National Hurricane Center map showing the forecast track of Hurricane Florence.
Source: https://www.nhc.noaa.gov/archive/2018/FLORENCE_graphics.php?product=5day_cone_with_line

The motivation for selecting two different county groups was to allow for comparing the difference in severity between the counties that were first struck by Hurricane Florence and the counties over which it passed as it exited the state several days later. Figure 1 highlights the locations of the selected counties in red, and Figure 2 shows the path of the hurricane beginning with landfall and continuing until it finally exits the western part of the state 2-3 days later.

Vulnerability data collection – The Social Vulnerability Index (SoVI), which is a composite measure made up of more than 30 variables that capture important socioeconomic and built environment characteristics, is frequently used to quantify the social vulnerability of U.S. counties to hazards, based on their socioeconomic and demographic features (Cutter et al., 2003). In order to further incorporate the severity measure into the calculation of risk, this study used the most recent SoVI data set, which is based on 2010-2014 Census data.

Exposure data collection – For the exposure calculation within the risk function, we used the estimated base county population data for 2018 and multiplied it by a sheltering needs factor to estimate the proportion of the population needing assistance. Given that Mileti et al. (1992) suggest that such a sheltering needs factor can vary from a minimum of 0.05 to a maximum of 0.20, we set the factor at 0.20 for the coastal counties and at 0.05 for the counties in the western mountains, in order to reflect the inherent differences in the population's hurricane response between these two regions. To perform a more detailed analysis of actual sheltering behavior, rather than to simply illustrate the underlying modeling approach, both a displacement factor and a more accurate measure of sheltering need should be provided, as in Arnette and Zobel's (2019) work in Colorado and Wyoming. Unfortunately, such data is not yet readily available for the state of North Carolina at this time.

Table 1. County-level data

County	SoVI	Population
Onslow	-3.67	177,772
Carteret	1.03	66,469
Henderson	1.7	106,740
Buncombe	0.45	238,318

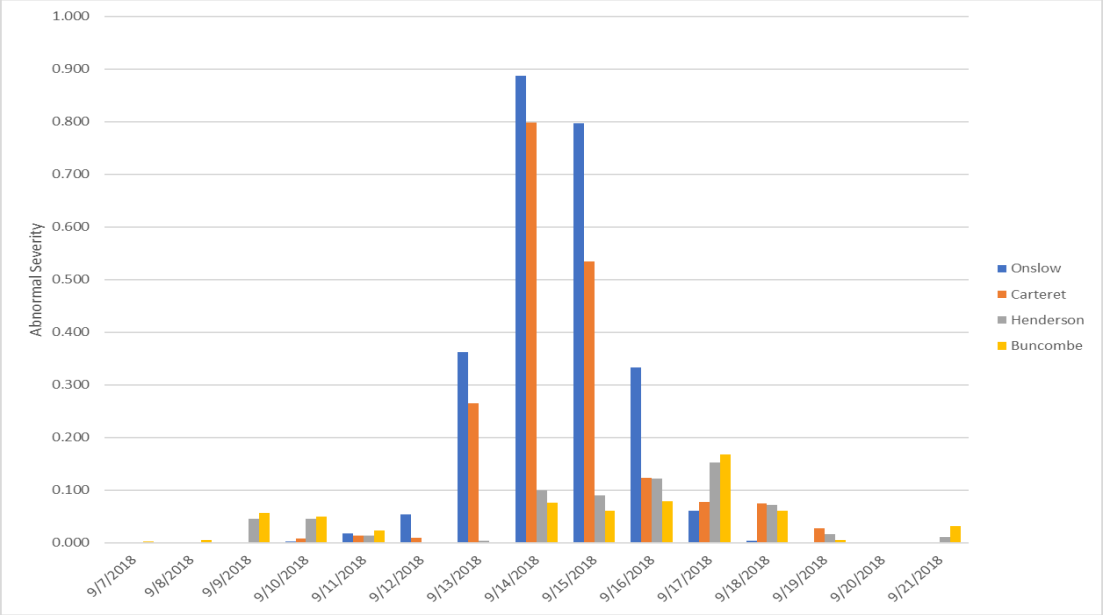


Figure 3. Abnormal severity related to Hurricane Florence

PRELIMINARY RESULTS

In order to generate a measure of the severity of the storm for each county during the specified time period, we calculated the average (normalized) wind speed and the average (normalized) precipitation over the five years previous to Hurricane Florence and created a weighted average of the two sub-measures, as in equation (3), using equal weights. This historical weighted average was used as a baseline against which the corresponding (normalized) values from September 2018 were compared. The amount by which the 2018 values exceeded the historical baseline was then taken as the actual measure of severity, with any values that fell at or below the historical weighted average being set to zero. Figure 3 presents the results.

It can clearly be seen in Figure 3 that September 14th is the day on which the hurricane reached its greatest severity along the coast, with slightly more severe weather being experienced in Onslow County. The severity in Carteret County, which is further north, drops off more quickly than that in Onslow County as the hurricane moves west and south. It can also be seen that the much reduced severity in Henderson and Buncombe counties grows in a similar way, but to a lesser extent and with a time lag of several days, as the depleted storm moves over that region. This behavior echoes expectations, given the forecast track of the hurricane as presented in Figure 2.

We then took the individual county-level severity values and incorporated them into an adjusted risk measure based on equation (2). Because we are considering only a single hazard event, and are characterizing the actual behavior of that event as it occurs, we assume a hazard probability of 1.0 and introduce the severity measure as the contribution of the hurricane to the local risk in each county:

$$R_i = S_i E_i V_i \tag{4}$$

The risk given by equation (4) thus reflects the relative extent to which each county was actually affected by the hurricane. Figure 4 subsequently illustrates the results of graphing the risk progression over the duration of the storm.

Because all three independent variables in equation (4) are normalized to the same [0, 1] scale, even a cursory comparison of Figures 3 and 4 clearly shows the significant influence of the severity measure on the measured risk value. The vulnerability also plays a significant role, however, as can be seen in the relative differences between the two coastal counties as well as those between the two mountain counties. Onslow County was subject to more severe conditions, yet its much lower population vulnerability leads to less overall risk during the height of the storm than Carteret County, despite its larger population. Similarly, despite its significantly lower vulnerability, Buncombe County's much larger population gives it a higher level of risk relative to that of Henderson County. In each case, it is obvious that the risk grows as the storm approaches and hits, and then drops as it moves away.

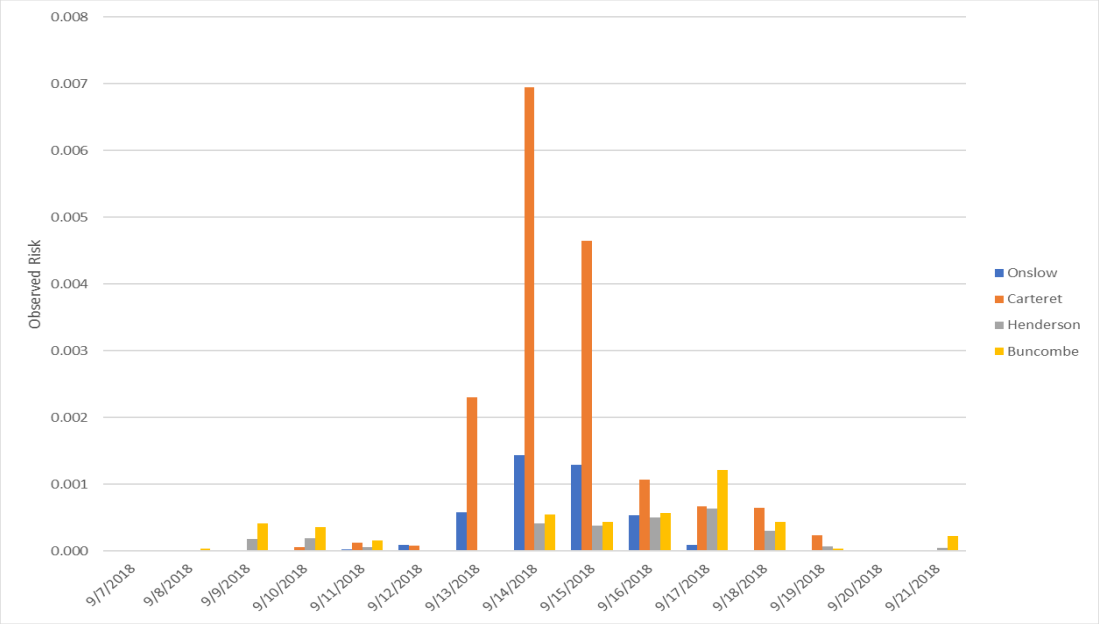


Figure 4. Observed risk related to Hurricane Florence

CONCLUSIONS

The purpose of this study is to provide a preliminary definition and illustration of a measure of the inherent severity of a natural hazard that can be incorporated into a localized measure of risk. Although a hazard can have a destructive impact on a given county, however, the inherent severity of that hazard is not the only factor affecting the risk to which that county's population is exposed. Indeed, the same level of severity may lead to different consequences in two different counties due to the relative vulnerability of the populations and the number of people who are actually exposed to the hazard event in a meaningful way.

It is important to recognize that this particular analysis was conducted in the context of a historical hazard event, and that the components of the severity measure were therefore given reasonably precise values. In order to calculate the risk for an upcoming event, not only would appropriate forecasts need to be available for the components' values, but also some notion of the probability of the event would need to be reintroduced into the discussion, since it may not affect a given community at all. This implies that the severity measure may also be effective in the context of slow-onset disasters, or at least disasters with less uncertainty, because it would be easier to make more accurate forecasts of future behavior. It also implies that scenario-based analyses on the severity of hazard events could give realistic insights about the possible outcomes of the hazard events that have possibility of occurrence in the future.

The focus of this paper was on a single natural hazard, and on the behavior of that particular hazard as it actually impacted several counties in North Carolina. This allowed us to assume a probability of occurrence of 1.0, and to effectively replace the hazard likelihood in equations (1) and (2) with the severity of the event. In general, however, if we wished to instead assess the future (forecast) severity and risk, we would need to also include the probability that the particular event would occur. This, in turn, would allow for considering the probability that different types of hazards might occur, and it would extend the applicability of the approach beyond just the set of indicator variables representing a single type of event.

Easily accessible weather data makes the severity calculation quick and easy to update, and the relative simplicity of both the severity (as defined above) and the risk function should make it very straightforward to extend the approach and adapt it to a variety of different problems. As a related future research direction, we are planning to include other accessible information, such as flood/storm warnings, into our severity measurement, and to consider other functional forms for the severity that may more effectively capture the relative contributions of its different characteristics in this context.

REFERENCES

Aerts, J. C., Lin, N., Botzen, W., Emanuel, K., & de Moel, H. (2013). Low probability flood risk modeling for New York City. *Risk Analysis*, 33(5), 772-788.

Arnette, A. N., & Zobel, C. W. (2019). A Risk-Based Approach to Improving Disaster Relief Asset Pre-Positioning. *Production and Operations Management*, 8(2), 457–478.

de Boer, J. (1990). Definition and classification of disasters: introduction of a disaster severity scale. *Journal of Emergency Medicine*, 8(5), 591-595.

de Boer, J., Brismar, B., Eldar, R., & Rutherford, W. H. (1989). The medical severity index of disasters. *Journal of Emergency Medicine*, 7(3), 269-273.

Chouinard, L. E., Liu, C., & Cooper, C. K. (1997). Model for severity of hurricanes in Gulf of Mexico. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 123(3), 120-129.

Cutter, S. L., Boruff, B. J. & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, 84, 242–261.

Gutenberg, B., & Richter, C. F. (1942). Earthquake magnitude, intensity, energy, and acceleration. *Bulletin of the Seismological Society of America*, 32(3), 163-191.

Mileti, D. S., Sorensen, J. H., & O'Brien, P. W. (1992). Toward an explanation of mass care shelter use in evacuations. *International Journal of Mass Emergencies and Disasters*, 10 (1), 25-42.

NHC (2018). Saffir-Simpson Hurricane Wind Scale. National Hurricane Center, NOAA. Retrieved from: https://www.nhc.noaa.gov/aboutsshws.php. Accessed on 2/13/2019.

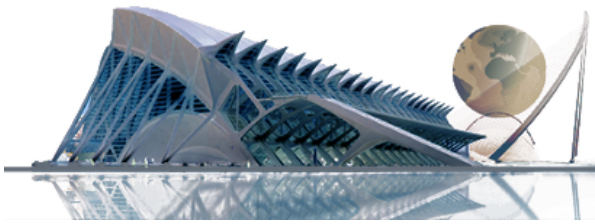
NWC (2018). Historic Hurricane Florence, September 12-15, 2018. National Weather Service. Available at: https://www.weather.gov/mhx/Florence2018. Accessed on 2/14/2019.

Rodríguez, J. T., Vitoriano, B., Montero, J., & Kecman, V. (2011). A disaster-severity assessment DSS comparative analysis. *OR Spectrum*, 33(3), 451-479.

Schembri, F. (2018). Deadly storms break records, damage facilities. *Science*, 361(6408), 1172-1173. DOI: 10.1126/science.361.6408.1172.

Willis, H. H., Morral, A. R., Kelly, T. K., & Medby, J. J. (2006). Estimating terrorism risk. *Rand Corporation*, Santa Monica, CA.

Zhang, N., & Huang, H. (2018). Assessment of world disaster severity processed by Gaussian blur based on large historical data: casualties as an evaluating indicator. *Natural Hazards*, 92(1), 173-187.



ISCRAM 2019
16 TH INTERNATIONAL CONFERENCE ON INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

Track 2.

Command and Control Studies

Chairs

Björn JE Johansson, *Linköping University, Sweden*

Peter Berggren, *Linköping University, Sweden*

Nicoleta Baroutsi, *Swedish Defence University*

Cause and Effect: A Qualitative Analysis of Obstacles to Information Sharing During a Regional Disaster Exercise

Abbas Ganji
University of Washington
ganjia@uw.edu

Tom Wilson
University of Washington
tomwi@uw.edu

Sonia Savelli
University of Washington
ssavelli@uw.edu

Dharma Dailey
University of Washington
ddailey@uw.edu

Mark Haselkorn
University of Washington
markh@uw.edu

ABSTRACT

After large-scale disasters, diverse partner agencies rely heavily on an information-sharing environment that supports collaborative work. In the U.S., this occurs under the Incident Command System (ICS), a structured organizational framework for coordinated action. We explore obstacles to information sharing and coordination observed at a county-level Emergency Operations Center (EOC) operating under ICS during the response phase of a large-scale regional disaster exercise. Textual observations collected in situ are analyzed for both the effect/manifestation and cause/source of barriers to information sharing. Two-thirds of barriers that manifest as computational issues are not caused by technology breakdowns, and a third caused by unclear processes manifest as computational issues. Overall, obstacles to collaborative work that appear to be related to computational issues are generally attributable to non-technical causes. This indicates that resources directed at improving collaborative management of disasters by enhancing technological capabilities are likely to be misdirected.

Keywords

Information Sharing; Disaster Response; Qualitative Analysis; Collaboration; Coordination

INTRODUCTION

Collaborative action during and after large-scale disasters is characterized by complexity, uncertainty, and the need for information. To achieve effective collaboration, independent yet partner agencies and organizations, each with their own jurisdictions, practices, policies, technologies, missions, and cultures, need to coordinate and share information. These independent and diverse partner agencies rely heavily on an information-sharing environment that supports collaborative work. In the U.S., this occurs under the Incident Command System (ICS), developed after 9/11 as a structured organizational framework for coordinated action. Although management of a disaster has numerous facets, a critical component is the capability of diverse federal, state, local, tribal, territorial, international, and private sector (FSLTTIP) entities to share information for activities such as damage assessment and response, asset requesting and tracking, and situational awareness. It is this information-sharing component, and the interoperability of the systems to support these activities, that is the focus of this paper.

In June 2016, Cascadia Rising, the largest regional disaster response exercise ever conducted in the Pacific

Northwest took place. This multi-state, international response to a massive earthquake and tsunami scenario provided the opportunity to observe the information sharing and interoperability among multiple partners during a complex, dynamic, non-routine event. Students were trained to conduct fieldwork study observations of emergency operations and coordination centers (EOCs/ECCs) as they activated to conduct and coordinate simulated field response operations both within their jurisdictions and with neighboring communities, state EOCs, Federal Emergency Management Agency (FEMA), and major military commands. Field study observations were conducted at state and county locations, providing an opportunity for analysis of information sharing and interoperability issues. Here we focus on a county EOC engaged in disaster response.

Prior work on information sharing during disaster response has tended to focus on the technological challenges, highlighting the technical issues that enable or inhibit information sharing, and viewing additional technology as the solution (Allen et al., 2014; Maitland et al., 2009; Reddy et al., 2009). Some researchers have investigated disaster response from an organizational perspective (Bharosa et al., 2010; Lee et al., 2011); however, there is still a preference for the development of information technologies to support the collaborative processes (Allen et al., 2014) rather than addressing the coordination of emergent groups during non-routine events characterized by complexity and uncertainty.

Based on previous studies (Haselkorn et al., 2014, 2015, 2016), we hypothesized that during the large-scale disaster exercise we would observe considerable informal information sharing as well as obstacles to information sharing that were not caused by technology, although they might manifest themselves that way. We posited that the uncertainty and complexity that characterizes non-routine events, even operating under ICS, would produce many obstacles to information sharing associated with human, organizational, and process issues. In this paper we unpack the symptoms that we observed and identify the etiology of the issues, thus allowing us to make suggestions to improve coordination and information sharing during the response phase of a disaster.

This paper is organized as follows: first, we briefly describe ICS and the exercise upon which this qualitative analysis is based; second, we review the relevant literature relating to information sharing and interoperability challenges unique to disaster events; third, we review our methods, including the development of a framework and management tool that supported qualitative analysis of information sharing during disaster response; fourth, we describe and discuss our results; and finally, we discuss the implications of our results and present additional research opportunities. Our analysis shows that the majority of barriers that manifest themselves as computational issues are, in fact, often due to a different underlying cause. This has implications for stakeholders, decision-makers, and practitioners working in disaster response roles, providing insight into more effective allocation of funds/resources to solve the relevant underlying issues, rather than those that may not be as problematic as previously assumed.

BACKGROUND

Disaster Response

A key element of disaster response in the U.S. post 9/11 is the ICS, a structured management framework for meeting the demands of small or large emergency situations (Department of Homeland Security 2008: 45-46). The ICS and its overarching plan, the National Incident Management System (NIMS), are mandated for use by all agencies that receive federal preparedness grants in the management of domestic incidents—which effectively means that the ICS will be activated in all emergencies (Dawes et al., 2004).

In the event of an emergency in the state of Washington, the ICS is implemented through EOCs—physical locations staffed by personnel who are structured according to the ICS. When incidents occur, they are typically managed at the lowest possible geographical, organizational, and jurisdictional levels—jurisdictions, working in collaboration with county and other local emergency management agencies, provide the initial response to the local incident. It is expected that local (city, county) departments assess what has happened in their area, including what is needed in terms of resources and action, and report this to the local EOC. In situations where the capacities or resources that are required exceed what the local jurisdictions can provide, the local jurisdiction may request assistance from the State Governor by proclaiming a local state of emergency. Depending on the scale of the disaster, the Governor may follow up with a State Proclamation of Emergency, initiating applying ICS at the state level, leading to the activation of a State EOC (SEOC) in order to respond to impending or existing disasters and emergencies. The proclamation by the Governor is a prerequisite for access to the full range of federal disaster recovery programs available to the state. Once established, the Washington SEOC supports state agency, local jurisdiction, and tribal nation operations in response to an emergency or disaster. The primary roles of the (S)EOC are to communicate, coordinate, dispatch, and track resources, and to collect, analyze, and disseminate information. At all levels, the ICS structure is designed to offer scalable components that function at a level consistent with the complexity of an event (Washington State 2008).

CASCADIA RISING: REGIONAL DISASTER EXERCISE

The four-day-long Cascadia Rising Disaster Exercise of June 2016 simulated the challenges and issues that would be faced in the event of a regional catastrophic earthquake. The scenario for the exercise was the most complex disaster scenario that emergency management and public safety officials in the Pacific Northwest could face—a Magnitude 9.0 subduction zone earthquake along the Cascadia Subduction Zone, followed just minutes later by a 100-foot tsunami:

> *"In the early morning hours (PDT) on June 7, 2016, a 9.0 magnitude earthquake resulting in the complete rupture of the 700-mile Cascadia Subduction Zone fault line occurs. The duration of the earthquake lasts over four minutes. The affected area encompasses 140,000 square miles directly impacting the states of Oregon and Washington and the Canadian province of British Columbia. Over 10 million people reside in the direct impact zone. The disaster causes widespread damage to critical infrastructures and the built environment and causes thousands of deaths and injuries."* (FEMA 2010)

Cascadia Rising was a multi-state effort involving agencies across the FSLTTIP. In Washington state, the main exercise was led by the Washington State Emergency Management Division. Exercise participants entered into an ICS structure to simulate the disaster response phase and engage in numerous post-disaster missions, many involving complex information-sharing scenarios, such as the introduction of assets from the federal government, the requesting of those assets by county EOCs through the SEOC, and the tracking of those assets by the SEOC and Washington Army National Guard (WANG). Each EOC was required to fully activate and staff their respective operations to manage disaster response within their jurisdiction while simultaneously coordinating with other EOCs and departments, agencies, and simulated first responders to meet exercise objectives.

A primary goal of Cascadia Rising was to test the effective coordination and integration of government agencies at all levels, working with the military, tribal nations, non-government organizations, and the private sector. Of particular interest were the core capabilities that enable this diverse community to conduct complex disaster operations as a unified team.

At the local and state level, one focus was the handling of resource requests and resource tracking during emergent and complex events. Of particular interest to organizers was the use of two internet-based information management systems intended to support these activities: (1) WebEOC—a mature system implemented with diverse configurations across many, but not all, of the participating agencies, and (2) the Washington Information Sharing Environment (WISE)—a more recent system, developed and used by the WANG to gather and make visible event-related information.

RELATED WORK

Coordination can broadly be defined as the "act of working together harmoniously" (Malone and Crowston 1990), and it is therefore central to work in organizations (Abraham and Reddy 2008). In proposing their coordination theory, Malone and Crowston (1990) described how effective coordination is invisible—it is poor coordination that becomes apparent and that we can observe. Coordination has been studied in various contexts in the literature, for example in hospital settings (Abraham and Reddy 2008), in geographically distributed research and development teams (Hinds and McGrath 2006), and in families (Leshed et al., 2014). Coordination in emergency management deals with specific challenges to information sharing according to the nature of emergency response. Characteristics, complexities, and obstacles in information sharing during emergency response have been extensively studied by Information Systems for Crisis Response and Management (ISCRAM) scholars and examined from various points of view (Barr et al., 2011; Gryszkiewicz and Chen 2010; Hellingrath and Widera 2011; Maitland et al., 2009; Scholl and Carnes 2017; Wikberg et al., 2017). Maitland et al. (2009) considered and compared information management barriers and information technology issues and identified their similarities and differences and requirements for resolving them. Gryszkiewicz and Chen (2010) proposed design requirements for information sharing in crisis management through semi-structured interviews with emergency managers in Sweden. Scholl and Carnes (2017) identified managerial challenges experienced by emergency responders and participants in the 2014 Oso/State Route 530 landslide disaster.

Non-routine events such as large-scale disasters are synonymous with uncertainty, and characterized by their complexity, the need for information, and the speed at which decisions need to be made (Allen et al., 2014). Mendonça et al. (2007) suggest several key characteristics of disaster management: First, the incidents occur relatively rarely, which limits the opportunities for training. Second, time constraints during an event leads to the convergence of planning and execution. Third, there is uncertainty as the evolution of the situation is unpredictable. Fourth, there is a need to manage interdependencies within a wide range of physical and social systems. And fifth, multiple decision-makers, groups, and organizations will need to come together and negotiate while also responding to the event. Such large-scale events necessitate collaboration and coordination among

multiple organizations because integrated information must be available in a timely fashion (Reuter et al., 2015).

At such times, organizations, each with their own distinct mission, culture, and working practices and which work far more independently on a daily basis, are expected and required to collaborate and coordinate, share information, and align under a common command structure. Although a mechanism such as the ICS provides such a structure and is in fact mandated in the U.S., other scholars point to the fallacy of applying a military-style structure in response to an incident, feeling that such an approach overlooks the need for collaboration, cooperation, and transparency by numerous organizations with different cultures and structures (Mendonça et al., 2007).

Empirical studies into coordination and information sharing during disaster response have tended to focus on technological challenges, giving less attention to the organizational aspects or coordination and information-sharing practices and policies. Such studies highlight technical issues that enable or inhibit coordination and information sharing, viewing technology as the solution (Allen et al., 2014; Maitland et al., 2009; Reddy et al., 2009). There has been a recent trend to investigate the organizational and social aspects of disaster response (Bharosa et al., 2010; Ley et al., 2014; Reuter et al., 2015). Nevertheless, the refinement of collaborative and coordination practices that are facilitated by information technologies is often overlooked in favor of the development of new or additional information technologies to support the collaborative processes (Allen et al., 2014).

Through observations of first responder exercises, Manoj and Baker (2007) identified three categories of communication challenges in emergency response: (1) technological—the challenges faced by the rapid deployment of interoperable communication networks after a disaster; (2) sociological—the challenges of obtaining and sharing information among ephemeral groups that are brought together in unfamiliar settings and times of uncertainty; and (3) organizational—challenges that arise due to the changes in management and decision-making frameworks that occur during a disaster. Although Manoj and Baker's work (2007) specifically examined the barriers to communication during disaster response, the technological and organizational categories provide a useful lens through which to look at interoperability and barriers to information sharing during non-routine operations and disaster response.

Technological Approaches

In the aftermath of the September 11, 2001, attacks in New York, the 9/11 Commission emphasized the importance of integrated, all-source information, and pointed out the U.S. failure to "connect the dots." This led to a focus on numerous technological approaches, such as: more and varied sensors to gather data, communication devices and networks to move that data, common operating pictures and visual analytics systems to help make sense of that data, dispatch systems to mobilize based on the situational awareness, and asset request and tracking systems to support the mobilization. The hope was that a single "killer app" incorporating all these capabilities would be used by all the relevant agencies, putting everyone on the same page in support of collaborative effort. (*Virtual USA* was an example of the Department of Homeland Security attempting such an effort.) In recent years, federal stakeholders have accepted that, for reasons that are often not technical in nature, it is unlikely that all relevant agencies and partners will adopt a single application, no matter how effective. This has led to the latest technological challenge—a distributed architecture that focuses on technical interoperability in order to link sensors, share data, and allow each partner agency to use whatever application they desire to make use of that data.

Technological approaches like these have been prevalent in the literature on improving EOC communication. For example, Dawes et al. (2004) focus on critical infrastructure damage after 9/11, and Graves (2002) explores the increased complexity of information technology and the need to integrate these technologies and devise contingencies for them in the face of disasters (Brooks et al., 2013). Similarly, Militello et al. (2007) view collaboration infrastructure to support post-disaster practices from the perspective of keeping technology functional, pointing out that updating shared displays are some of the first tasks to be neglected—particularly if the systems are not used outside of disaster response operations.

Organizational and Process Approaches

During disaster response, the ICS framework alters the day-to-day working practices of government agencies and organizations in the profit and non-profit sectors. It has long been established that "every emergency is local" (Dynes et al., 1972) and the ICS is often initially activated at the lowest geographical, organizational, and jurisdictional level. However, since the majority of the funding for large-scale disasters comes from the federal government, tensions between local and federal participants may inhibit information sharing and require state-level participants to mediate tensions while also dealing with the local aspects of the emergency (Brooks et al.,

2013).

Haselkorn et al. (2014, 2015) and Timmons (2007) found that at the individual level, first responders tend to revert to their normal information-sharing practices during times of crisis rather than modify their practices to align with the crisis response framework (i.e., ICS) (Brooks et al., 2013). This "normal" sharing is often described as "informal" communication—relying on personal contacts and existing trust relationships—as opposed to formal communication coming through the predesignated command structure and mediated by government information systems. In Norway, which adopts an equivalent structure to ICS, Rimstad et al. (2014) studied the information flows during the response to the 2011 terrorist attacks in Oslo and on the island of Utoya. Despite the formal organizational structure imposed by the ICS equivalent, important information was also obtained through personal social networking between responders. Similar informal communications were observed by Bharosa et al. (2010) with personal phone calls among Dutch responders facilitating information flows during a crisis response exercise. Schraagen et al. (2010) examined information sharing during crisis management and compared rapidity and accuracy of information sharing between hierarchical and network team organizations through a control experiment (Altay and Labonte 2014). They concluded that network teams were faster, more accurate, and shared more information in difficult scenarios.

Organizational challenges also arise when the plans laid out in emergency response documents are not sufficient or suitable to deal with a specific situation that may arise post-disaster. For example, through analysis of multiple emergency response exercises, Brooks et al. (2013) found that emergency managers were often repairing disrupted organizational routines by bridging unforeseen gaps in the emergency response plans. Here we can draw parallels with Suchman's *Plans and Situated Actions* (Suchman 1987, 2006) whereby there is a difference between the plans that are made in advance and the actions that are required *in situ* at a particular time—although the plans and processes exist, the situations are dynamic and reliant upon interdependence between heterogeneous organizations. Consequently, it is impossible to plan for all contingencies and a degree of ongoing improvisation is necessary (Reuter et al., 2015). The value of emergency response planning is the thought that goes into it, but plans cannot guide a specific action during a specific event—preparedness is best achieved through practice of the plans and their contingencies (Dawes et al., 2004). Mendonça et al. (2007) view improvisation from the technological perspective, using the term *emergent interoperability* to describe the information technologies that need to be "mixed and matched" to support the accomplishment of disaster response tasks by individuals who are part of various organizations each with their own distinct practices and adhocracies.

This background information and our own work identify many obstacles to information sharing associated with human, technological, organizational, and process issues. The Cascadia Rising exercise provided us with the opportunity to directly observe the obstacles to information sharing. Then, using a qualitative analysis approach, we unpacked the symptoms that we observed and identified the etiology of the issues, allowing us to suggest improvements to coordination and information sharing during disaster response.

METHODS

Data Collection

Supporting Researchers in Multiple Roles

The decision to study a multi-state, multi-actor, multi-location, large-scale exercise brought several opportunities and challenges. Our research design had to: (1) be unobtrusive by allowing our researchers to perform within the exercise as observers and evaluators—pre-defined accepted roles within such exercises; (2) obtain rich text and contextual data that would support post-event analysis useful to a diverse group of faculty and research scientists; and (3) capture work and information sharing across multiple sites. With strong support from the Washington State exercise team,[1] our researchers were included on the exercise evaluation team, attended exercise training sessions, and were embedded at a number of key state and local sites. To prepare for the pre-defined role of observer/evaluator, research team members without prior emergency management experience were required to meet minimum qualifications set by FEMA, illustrating a basic knowledge of emergency management. All observers completed the 100, 200, and 300-level ICS online training, and attended a day-long training at the SEOC. In this way, our team was able to contribute to the state's After-Action Report (AAR), the mechanism for sharing lessons learned across the emergency management community.

[1] Special thanks to Ed Taylor, State Exercise Program Manager, and Jason McMillan, Kitsap County Operations Coordinator.

Fieldnote Jotting Through Slack

We used *Slack*, a communication and messaging tool popular with small and medium sized companies (Benner 2017), for capturing real-time observations and for more general coordination among field observers. Slack "channels," visually distinct conversation threads, were set up prior to the exercise for each location with a team member.

One experienced field researcher trained in ethnographic field work was deployed to Kitsap County. In the course of the exercise where many people were working on computers, she found it was unobtrusive to make fieldnote jottings on her computer as events unfolded (Emerson et al., 1996). It was then easy to paste fieldnote jottings into the Slack channel for her county at brief and regular intervals. This had two unexpected advantages. First, Slack has searchable archiving features built in, making it relatively easy to work with the data repository. Second, researchers at multiple sites—and from multiple disciplines—were able follow data collection in near real time. In several instances this led to tracking and follow-up clarification (i.e., better documentation) as information moved (or not) across exercise sites. Importantly, it also led to data collection of more depth and more diverse topics, as remote researchers with different interests requested follow-up information on events as they occurred.

Qualitative Analysis Approach

The qualitative analysis reported here focused on the Slack-recorded observations from the one trained field researcher at the *Kitsap County EOC*. Prior to coding of these observations all names of emergency response personnel participating in the exercise were anonymized to protect their identities. While Slack is an online tool its security program is aligned with ISO 27000, AICPA Trust Service Principles, and NIST standards. All data in transit and at rest is encrypted and only trained students and faculty were granted access to Slack channels related to the Cascadia Rising Exercise. A research group of graduate and undergraduate students met weekly for two quarters (20 weeks) to learn and then conduct the process of qualitative data analysis using the Kitsap EOC observations. To better understand the observations of the activities at the county EOC, all class participants completed the 100-level ICS online training. A team of four—one undergraduate student, two graduate students, and one university research scientist—was selected to form the coding team. The analysis of the Kitsap field notes began with an initial reading of the observations, as recorded, to familiarize the four analysts with the substance of the data, understand the flow of communication and information sharing activity within the Kitsap County EOC, and begin to identify recurring themes (Strauss and Corbin 2008). The four analysts worked individually and then jointly on close readings of the observations to identify text blocks representing incidents of information sharing or other coordination activities performed by the exercise participants. This allowed the researchers to reduce the data to only those portions of text related to the exercise, which facilitated the coding process described below.

The team began the exploratory, open-coding analysis by iteratively going through data, asking questions, and making comparisons to develop a common understanding of the observations and to identify the emerging themes (Strauss and Corbin 2008). The first theme to develop resulted from asking the question, "what happened?" In other words, "what is the effect or manifestation of the information sharing barrier that was observed?" Merriam-Webster defines an effect as "something that inevitably follows an antecedent (such as a cause or agent). Similarly, asking questions, such as "how" or "why" the effect occurred was used to determine the cause or source of the observed effect. One way to think about the cause-effect relationship between the information sharing breakdowns is to consider the genotype-phenotype relationship (Hollnagel & Marsden, 1996). The effect, like the phenotype, is observable; while the genotype, like the cause, can only be inferred. In this analysis, we first identified the observable barriers of information sharing breakdowns as "effect", then during the iterative, open-coding analysis, we divided the effect theme into seven different categories (see Table 1). When developing the categories for the "cause" theme, we found that while potential causes of information sharing breakdowns are different from the observable (effect) resulting from information sharing breakdowns, we could use the same categories. Accordingly, the cause/source theme used the same codebook, but this time it was used to infer possible causes behind the observed barriers. In some cases, cause and effect were coded similarly which means the observed barrier (effect) was caused from similar category. For example, Observation #11 ("*Planning GIS is trying to create a damage map, but there is a technical issue due to a recent update."*) was coded by computational mechanism issue as effect, while more investigation showed that the source of this observation is computational mechanism issue too. The above process occurred over several weeks, with all team members refining and agreeing upon the codes to be used in the analysis for classifying causes and effects of barriers to information sharing.

Qualitative Analysis Tool

To support the closed coding (using the coding scheme), one of the analysts designed and created programmed Excel spreadsheets, named Code Wizard, to support collaborative qualitative coding (Ganji et al. 2018). Code

Wizard consists of two main spreadsheets: one for individual coding performed by coders individually and independently, and one for aggregating coded data for team discussion meetings. Code Wizard, which was evolved during the study, provided the following benefits: (1) minimized training for coders to perform collaborative coding; (2) allowed the team to easily modify, remove, or add a selected barrier; (3) enabled real-time changes during discussion sessions; (4) provided insights into the reasons behind coders' disagreements to be discussed in weekly discussion meetings; and (5) accelerated the agreement level of coded issues by assigning different colors to the categories, allowing the agreement to be easily visualized (See more details in Ganji et al. 2018). Figure 1 presents a sample of the spreadsheet used by each of the analysts.

	Time/ Date	Unit of Analysis	Link to Source	Categories	
				Cause	Effect
1	10:08 6/7/16	It is not clear if the information is from a citizen or someone else.	go to	Paper Mechanism Issue	Source Breakdown
2	10:08 6/7/16	The agency that the information is coming from is not on the form.	go to	Paper Mechanism Issue	Source Breakdown
3	10:08 6/7/16	I ask about this and the player shows me other written forms that similarly require a lot of guessing because the way they are filled out is vague.	go to	Content Breakdown	Content Breakdown
4	10:20 6/7/16	One of the planning team goes to track down who handed off two confusing paper information forms. Guesses are made based on pen color and handwriting as to who to talk to.	go to	Source Breakdown	Content Breakdown

Figure 1. Qualitative Analysis Tool (individual spreadsheet) Used by Each Analyst to Code the Data

Once all four analysts coded the Slack data, results were merged into one spreadsheet showing the codes assigned by each analyst (see Figure 2). The merged spreadsheet was also designed to calculate Fleiss' kappa (Fleiss et al., 1969) as a statistical index for evaluating the inter-rater reliability coefficient of investigated text data. Using this merged spreadsheet, the coding team met weekly to review and discuss coding choices, allowing analysts to ask questions, make comparisons, and iterate until they achieved an inter-rater reliability of $\kappa = 0.80$[2]. The team conducted coding data in two steps. First, the analysts coded data for the effect theme in three rounds of coding to meet the acceptable inter-rater reliability threshold. Second, two rounds of coding were performed similarly to identify types of causes/sources to achieve our threshold. The themes that emerged from our analysis are detailed below and include excerpts of the observations to illustrate findings.

[2] Although there is no general agreement on a minimum Fleiss' kappa value for a strong consensus, exceeding 0.8 is widely considered as "almost perfect agreement" in the literature [14].

	Time	Unit of Analysis (Help? Codebook)	Link to Source	Coder 1 Primary	Coder 2 Primary	Coder 3 Primary	Coder 4 Primary	Agreement (Pi)
1	10:08 6/7/16	It is not clear if the information is from a citizen or someone else.	go to	SB	SB	SB	SB	1.00
2	10:08 6/7/16	The agency that the information is coming from is not on the form.	go to	CT	SB	SB	CT	0.33
3	10:08 6/7/16	I ask about this and the player shows me other written forms that similarly require a lot of guessing because the way they are filled out is vague.	go to	CT	CT	CT	CT	1.00
4	10:20 6/7/16	One of the planning team goes to track down who handed off two confusing paper information forms. Guesses are made based on pen color and handwriting as to who to talk to.	go to	CT	CT	PM	PM	0.50
5	10:20 6/7/16	Another confusing message doesn't have a log number from the message center, so it was not routed through the center. So, the planning players are unsure who to go back and get information from.	go to	CT	CT	PM	SB	0.17

Figure 2. Qualitative Analysis Tool (merged spreadsheet) Used to Discuss Coding Choices by all Analysts and Achieve Agreement

RESULTS

Our analysis revealed that observations recorded during two days of the Cascadia Rising regional disaster exercise at Kitsap County represented 45 issues or breakdowns in cooperation and information sharing. Further analysis found that these issues could be coded using seven categories for both effect (i.e., how the issue manifested) and cause (i.e., the source of the issue). See Table 1 for the seven categories used to code the issues as causes and effects.

Category	Definition
Computational Mechanism Issue (CM)	Perhaps poorly designed computer-based form or system
Content Breakdown (CT)	Unclear or incomplete content; missing information
Coordination Breakdown (CD)	Individuals/groups knew the process, but process did not work, or they did not follow it
Interoperability (IO)	Systems do not work well together, may occur when two systems have two different standards
Paper Mechanism Issue (PM)	Paper form not working, perhaps due to poor design or missing information
Source Breakdown (SB)	Source not identified; whenever we think something went wrong regardless of paper or system
Unclear Process (UP)	People unsure how to do things due to unclear or undocumented process including the lack of training

Table 1: Classification System and Definitions developed to identify cause-effect relationships of information sharing

breakdowns

Almost half of all obstacles to information sharing were coded as manifesting as either computer system issues (13) or coordination issues (9), while coordination issues (10) and unclear processes (12) were coded as the actual cause of almost half of all information-sharing breakdowns. Very few breakdowns manifested as issues with paper mechanisms (1), while content (2) and information source issues (2) caused very few breakdowns.

Table 2 shows those observations manifesting as computational mechanisms issues[3]. Unclear processes were the cause of four of these 13 issues. Upon first reading, these issues may appear to be caused solely by a technical issue. For example, Observation #14 includes several mentions of technology (e.g., "multiple systems", "GIS", and "Adobe PDF viewer"). However, looking beyond these surface detail and examining additional text that preceded and followed Observation #14, the coders classified the cause as an "unclear process," explaining that if exercise participants understood how and which systems to use, the inability to coordinate and share information may have been overcome. Similarly, for Observations #15, #16, and #19, participants are having difficulty with the system designed to record damages on a regional map. While one may infer the cause as a computational mechanism issue, the analysis team explained that had the process been more clearly conveyed they would not need to spend valuable time trouble-shooting the system to determine if the feature worked correctly, hence they classified the cause as "unclear process."

Three of the manifestations of computer system mechanisms were classified as caused by issues of interoperability. Observation #13, #22, and #45 describe issues related to the inability of systems to share data across disparate systems. In the case of Observation #13, both versions of WebEOC had the ability to track events and resources, but a standard definition of "significant event" was not available. As a result, an event that was tracked in one version of WebEOC could not be tracked in a different version WebEOC.

Only one time, was an issue with "coordination" identified as the cause of a "computational mechanism" manifestation (see Observation #33 in Table 2). In this case, functionality which was expected to be available by the start of the exercise, was not implemented. Throughout the exercise it because apparent that tracking all issues, assign a priority, and sort on the priority was a function that would provide great value to the resource scheduling team.

Finally, five of the 18 manifestations of "computational mechanism" issues were also classified as caused by "computational mechanism" issues. Various technical issues are explicitly called out in the observation, and a thorough reading of the Slack jottings surrounding these issues, resulted in the analysis team agreeing that these issues were caused by a failure of technology.

#	*Observation*	*Cause*
11	Planning GIS is trying to create a damage map, but there is a technical issue due to a recent update.	Computational Mechanism Issue
13	The Deputy PIO is working on an internal communication issue. The PIOs would like to use WebEOC to communicate with each other internally. That functionality has not been implemented for Kitsap County in the same way it works at Camp Murray. These PIOs want to track things in WebEOC that don't quite qualify as "significant events" but may be bits of information that they would get information requests about.	Interoperability
14	Looks like multiple systems are in play for the road damage. Original maps are created in GIS. Trying to get the details without being too pushy. Seems some edits are also being made in an Adobe PDF viewer. Though, the player I spoke with said, "It's not doing what I want it to do.	Unclear Process
15	I've been looking at the Public Works trying to do rapid mark up on PDFs of maps. It doesn't seem to be working.	Unclear Process
16	A National Guard player is at the smart screen loading a map. He is attempting to edit the map which is a PDF by drawing over it with a stylus. "It's not doing what I want it to do."	Unclear Process
17	He will also convert it to a JPG so it can be shared.	Computational Mechanism Issue

[3] In order to fully understand an observation, the analysis team often referred back to Slack jottings that both preceded and followed the observations shown in the table.

18	There is a problem with editing the map in the PDF viewer. If you change the map view, the edits above it will be off.	Computational Mechanism Issue
19	[participant] from county public works and a National Guard player are troubleshooting the map on the smart screen. They are looking up the smart screen manual on [participant] phone. It seems that the smart screen should support easy and fast markup of the map so that Public Works can quickly get out information to crews of where damage is. The national guard player is going through several permutations, but none of them seem to work. For rapid assessments and documentation, it seems this system needs some reworking.	Unclear Process
22	Kitsap assessment tool has a web-based tool to upload a situation report. The web app is partially broken. A recent ArcGIS system update broke the ability to talk directly to the damage assessment collection tool. One of the National Guard players: The EOC GIS displays are all different, no standard.	Interoperability
26	Message forms are coming in, but it can't be brought in to the GIS tool. Data is being put into the GIS system by hand.	Computational Mechanism Issue
27	Can't download data from the web app. A CERT volunteer and the GIS planner continue to work on fixing the system.	Computational Mechanism Issue
33	The WebEOC functionality they were looking for (logging lower priority information) probably won't be implemented during the exercise.	Coordination Breakdown
45	The web-based tool is pre-loaded with important locations such as drug stores, food stores and fire stations throughout the county. It is designed to work with their GIS, though there was a hiccup with that yesterday.	Interoperability

Table 2: Observations manifesting as Computational Mechanism Breakdowns and their causes as identified by the coding analysis team.

Table 3 represents the nine observations that manifested as coordination breakdowns. Seven of these nine issues were also caused by coordination breakdowns. Observation #9 is the description of the process where the county commissioner, officially declares a "state of emergency." This declaration is required in order for other tasks to be completed, thus many people are idle due to the breakdown in coordination. The two interoperability causes identified in Table 3, Observation #29 and #34, are related to operational and technical interoperatbility issues, respectively.

#	***Observation***	***Cause***
9	This declaration could be made locally by the county commissioner, but so far that has not happened. The commissioner is inaccessible which is delaying the declaration. This is delaying some of things that need to occur.	Coordination Breakdown
12	Several stickers are beings added retroactively to the map.	Coordination Breakdown
25	Too few GIS workstations here.	Coordination Breakdown
28	We have a very incomplete [picture] of what the damage is in the county.	Coordination Breakdown
29	ACCs and Police Departments are overwhelmed.	Interoperability
30	Plans are not solidified on commodities for citizens.	Coordination Breakdown
34	Damage assessment, some blips some parts still not talking to each other.	Interoperability
35	The message center is not operational today.	Coordination Breakdown
36	Still use the message forms. Deliver them where they need to go.	Coordination Breakdown

Table 3: Observations manifesting as Coordination Breakdowns and their causes as identified by the coding analysis team.

To summarize, a qualitative analysis, grounded in the data, revealed that breakdowns in information sharing among people and agencies had many symptoms and many causes, and they were not always aligned. Two-thirds of barriers that manifested themselves as computer systems issues were not caused by computer systems issues, and a third caused by unclear processes manifested as computer systems issues. In the following section we discuss what results like this one mean for improving collaborative management of disasters.

DISCUSSION

In this qualitative investigation of the response to a large-scale regional disaster, focused on the activities of a county EOC, we sought to identify the cause-effect relationships that made it difficult to achieve desired information sharing. Specifically, we identified the observable effects of information sharing breakdowns and then inferred possible causes of these breakdowns, using the classification system described above. While not all may agree with the particular classifications, we believe that the qualitative coding methodology and the analysis tool used here contributes to the knowledge regarding the causes of breakdowns in complex socio-technical crisis management systems.

According to the *Cascadia Rising Disaster Exercise After Action Report* (FEMA 2016), a long history of regional coordination and collaboration led to overall successes during the exercise, improving situational awareness and decision-making capabilities and bridging gaps in communications and problem-solving. Still, as we observed at the county-level EOC and as was acknowledged in the AAR, there were significant obstacles to information sharing and coordination. In fact, the general conclusion of the Cascadia Rising After Action Review was that we as a regional community are not prepared for a disaster of this magnitude. But where should we focus our investments and energies to become better prepared?

This study suggests that in a crisis information sharing environment, computer systems are more likely to manifest a problem than they are to be the cause of it. Results indicate that although the effect of an obstacle to information sharing or coordination may be related to a computer system or software, the cause of the problem is more often than not due to other factors. Computer issues were as likely to be caused by unclear processes as technical issues. Some of these issues could be attributed to individuals' lack of training with such systems, exacerbated by the infrequency of using computer systems that are designed for or being adapted for use during disaster response. Overall, obstacles to collaborative work that appear to be related to computational issues are generally attributable to non-technical causes. This indicates the danger in attempting to improve collaborative management of disasters by enhancing technological capabilities. Interestingly, when we discussed this conclusion with disaster practitioners, their general reaction was, "That's not surprising. We knew that." Yet the investment in technical fixes to crisis collaborative systems continues to be considerable.

Coordination issues in support of collaborative work could be attributed to various factors. The extent of the Cascadia Rising exercise scenario meant that the state had to call upon federal and military assistance in order to respond to the disaster. Consequently, there were individuals who were working together for the first time and unfamiliar with operational procedures involving these new players. Such challenges are common in disaster response due to different organizational cultures and distinct individual and coordinative work practices Ley et al., 2014). The shared ICS structure is designed to overcome some of these challenges, but in many cases did not achieve this, either because several jurisdictions used modified versions of the ICS—which is acceptable but can lead to problems with coordination (Lee et al., 2011)—or because ICS is more effective as a going-in position than as a playbook to manage unexpected challenges. Our results indicated that coordination breakdowns were common, about 1 in 5 of all obstacles whether viewed as cause or effect. Coordination issues were the most significant cause of missing content. This missing information meant that necessary collaborative work was delayed or could not be completed.

Interoperability issues, viewed not just as machine issues, were also significant. There are many levels of interoperability, from technical levels that link networks and data to mission-centric operational and policy levels of interoperability (Haselkorn et al., 2016). While prior studies of disaster systems have focused on "lower-level" technological interoperability problems of data sharing and networking, we took a broad definition of "system" and included "higher-level" interoperability such as conflicting policies or misaligned practices. From this perspective, interoperability was a prevalent cause (1 in 5) but not as prevalent an effect (about 1 in 10). As the literature suggests, response emergency managers, faced with interoperability issues, improvise and devise low-tech workarounds to support information sharing (Brooks et al., 2013). During Cascadia Rising we also saw evidence of this. For example, as response teams were trying to find geographic information system (GIS) data, they discovered that there was no data clearinghouse that could be used across organizations. This led responders to improvise—reaching out to regional workers they had connections with and finding suitable data. They then, however, struggled mightily with integrating this data into a useful situational picture.

More than a quarter of all information breakdowns we observed were categorized as being caused by an unclear process. Supporting this, the AAR found that almost all jurisdictions reported a lack of understanding of the resource request process, finding that in some cases the personnel had not received adequate training required to make and track resource requests (FEMA 2016). Like the improvisation described above, this further speaks to the fact that resources should be allocated to support how people actually work—informally based on past shared experiences and trust relationships—rather than on new technology that changes, and constraints work processes. Unclear processes were the single biggest cause of obstacles to information sharing in support of collaborative

crisis work. Introducing new technology that impacts how people work is likely to make this problem worse, not better.

CONCLUSION

State-of-the-art human centered design methods are based on the perspective that technology is a tool in support of accomplishing human missions and meeting human needs. Without an alignment of human issues such as shared missions, policies, and operational concepts, no amount of technology can achieve effective collaborative work. Operational professionals such as those working heroically to minimize the destructive impact of earthquakes and other hazards know this intimately. This study found information-sharing obstacles associated with computer systems to be the single most **visible effect** during a major crisis exercise, but they were far from the most significant **underlying cause**. This evidence, in support of what practitioners already know from experience, argues for a shift in how we invest in our collaborative crisis management "systems."

REFERENCES

Abraham, J., & Reddy, M. C. (2008, November). Moving patients around: a field study of coordination between clinical and non-clinical staff in hospitals. In *Proceedings of the 2008 ACM conference on Computer supported cooperative work* (pp. 225-228). ACM.

Allen, D. K., Karanasios, S., & Norman, A. (2014). Information sharing and interoperability: the case of major incident management. *European Journal of Information Systems*, 23(4), 418-432.

Altay, N., & Labonte, M. (2014). Challenges in humanitarian information management and exchange: evidence from Haiti. *Disasters*, 38(s1), S50-S72.

Barr, J. L., Peddicord, A. B., Burtner, E. R., & Mahy, H. A. (2011, May). Current domain challenges in the emergency response community. In *Proceedings of the 8th International ISCRAM Conference – Lisbon* (Vol. 1).

Benner, K. (2017). Slack, an upstart in messaging, now faces giant tech rivals. *The New York Times* (April 12).

Bharosa, N., Lee, J., & Janssen, M. (2010). Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: Propositions from field exercises. *Information Systems Frontiers*, 12(1), 49-65.

Brooks, J. M., Bodeau, D., & Fedorowicz, J. (2013). Network management in emergency response: Articulation practices of state-level managers—Interweaving up, down, and sideways. *Administration & Society*, 45(8), 911-948.

Corbin, J., & Strauss, A. (2008). Basics of qualitative research: Techniques and procedures for developing grounded theory.

Dawes, S. S., Birkland, T., Tayi, G. K., & Schneider, C. A. (2004). Information, Technology, and Coordination: Lessons from the World Trade Center Response. Center for Technology in Government, University at Albany, SUNY, Albany, New York.

Department of Homeland Security. (2008). National Incident Management System. https://www.hsdl.org/?abstract&did=232899.

Dynes, R. R., Quarantelli, E. L., & Kreps, G. A. (1972). *A perspective on disaster planning (No. DRC-SER-11).* Ohio State University, Columbus Disaster Research Center.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (1996). Writing Ethnographic Fieldnotes. *Contemporary Sociology* 25, 705. http://doi.org/10.2307/2077613.

FEMA. (2016). Cascadia Rising 2016 Exercise Joint Multi-State After-Action Report (AAR).

FEMA. (2010). Exercise Plan. 1–8. Retrieved from FEMA. (2010). Exercise Evaluation Plan (pp. 1-13). Retrieved from FEMA. (2010). Designing a Functional Exercise (pp. 1-35). Retrieved from FEMA. (2010). Exercise Enhancements (pp. 1-22). Retrieved from FEMA. (2010). Exercise Evaluation (pp. 1-34).

Fleiss, J. L., Cohen, J., & Everitt, B. S. (1969). Large sample standard errors of kappa and weighted kappa. *Psychological bulletin*, 72(5), 323.

Ganji, A., Orand, M., & McDonald, D. W. (2018). Ease on Down the Code: Complex Collaborative Qualitative Coding Simplified with 'Code Wizard'. *Proceedings of the ACM on Human-Computer Interaction*, *2* (CSCW), 132.

Graves, R. J. (2002). Key Technologies for Emergency Response. In *Proceedings of ISCRAM, 2004, Brussels, May 3-4* (pp. 133–138).

Gryszkiewicz, A., & Chen, F. (2010). Design requirements for information sharing in a crisis management command and control centre. In *7th International Conference on Information Systems for Crisis Response and Management, ISCRAM 2010; Seattle, WA; United States; 2 May 2010 through 5 May 2010*.

Haselkorn, M., Butler, K., & Zachry, M. (2014). MOISA 2: for Maritime Security, Safety, and Resilience. A report prepared for the Department of Homeland Security Interagency Operations Center, the National Maritime Intelligence-Integration Office, and the Program Manager for the Information Sharing Environment.

Haselkorn, M., Butler, K., Zachry, M., Zito, B. Savelli, S., Kirby, E., & Braxton, M. (2015). Maritime operational information sharing analysis: Year 2 (MOISA 2). Prepared for the Department of Homeland Security Interagency Operations Center, the National Maritime Intelligence-Integration Office, and the Program Manager for the Information Sharing Environment.

Haselkorn, M., Zachry, M., Savelli, S. Zito, B., Braxton, M., & Butler, M. (2016). Project interoperability in the Puget Sound: A regional mission-centric perspective on information sharing and safeguarding. Prepared for the Program Manager Information Sharing Environment.

Hellingrath, B., & Widera, A. (2011, May). Survey on major challenges in humanitarian logistics. In *Proceedings of the 8th International ISCRAM Conference* (pp. 1-5).

Hinds, P., & McGrath, C. (2006, November). Structures that work: social structure, work structure and coordination ease in geographically distributed teams. In *Proceedings of the 2006 20th anniversary conference on computer supported cooperative work* (pp. 343-352). ACM.

Hollnagel, E. & Marsden, P. (1996). Further development of the phenotype-genotype classification scheme for the analysis of human erroneous actions. *Institutes for Systems, Informatics and Safety, Human Reliability Associates, Ltd., UK*.

Lee, J., Bharosa, N., Yang, J., Janssen, M., & Rao, H. R. (2011). Group value and intention to use—A study of multi-agency disaster management information systems for public safety. *Decision Support Systems*, 50(2), 404-414.

Leshed, G., Håkansson, M., & Kaye, J. J. (2014, February). Our life is the farm and farming is our life: home-work coordination in organic farm families. In *Proceedings of the 17th ACM conference on computer supported cooperative work & social computing* (pp. 487-498). ACM.

Ley, B., Ludwig, T., Pipek, V., Randall, D., Reuter, C., & Wiedenhoefer, T. (2014). Information and expertise sharing in inter-organizational crisis management. *Computer Supported Cooperative Work (CSCW)*, 23(4-6), 347-387.

Maitland, C., Ngamassi, L., & Tapia, A. (2009, May). Information management and technology issues addressed by humanitarian relief coordination bodies. In *Proceedings of the 6th International ISCRAM Conference*.

Malone, T. W., & Crowston, K. (1990, September). What is coordination theory and how can it help design cooperative work systems? In *Proceedings of the 1990 ACM conference on computer-supported cooperative work* (pp. 357-370). ACM.

Manoj, B. S., & Baker, A. H. (2007). Communication challenges in emergency response. *Communications of the ACM*, 50(3), 51-53.

Mendonça, D., Jefferson, T., & Harrald, J. (2007). Collaborative adhocracies and mix-and-match technologies in emergency management. *Communications of the ACM*, 50(3), 44-49.

Militello, L. G., Patterson, E. S., Bowman, L., & Wears, R. (2007). Information flow during crisis management: challenges to coordination in the emergency operations center. *Cognition, Technology & Work,* 9(1), 25-31.

Reddy, M. C., Paul, S. A., Abraham, J., McNeese, M., DeFlitch, C., & Yen, J. (2009). Challenges to effective crisis management: using information and communication technologies to coordinate emergency medical services and emergency department teams. *International Journal of Medical Informatics*, 78(4), 259-269.

Reuter, C. (2015). Emergent collaboration infrastructures: technology design for inter-organizational crisis management. Springer.

Rimstad, R., Njå, O., Rake, E. L., & Braut, G. S. (2014). Incident command and information flows in a large-scale emergency operation. *Journal of Contingencies and Crisis Management,* 22(1), 29-38.

Scholl, H. J., & Carnes, S. L. Managerial Challenges in Early Disaster Response: The Case of the 2014 Oso/SR530 Landslide Disaster.

Schraagen, J. M., Veld, M. H. I. T., & De Koning, L. (2010). Information sharing during crisis management in hierarchical vs. network teams. *Journal of contingencies and crisis management*, 18(2), 117-127.

Suchman, L. (2006). Human-Machine Reconfigurations: Plans and Situated Actions (Learning in Doing: Social, Cognitive and Computational Perspectives). Cambridge University Press. doi:10.1017/CBO9780511808418.

Suchman, L. A. (1987). Plans and situated actions: The problem of human-machine communication. Cambridge University Press.

Timmons, R. P. (2007). Interoperability: Stop blaming the radio. Naval Postgraduate School, Monterey, California, Center for Homeland Defense and Security.

Washington State. 2008. THE BASIC PLAN. 3-15.

Wikberg, P., Andersson, D., & Johansson, B. (2017). Assessing command and control team's performance and agility. In *Proceedings of the 14th ISCRAM Conference – Albi, France, May 2017*.

Inter-Organisational Learning – A Review of Knowledge Sharing in Post-Exercise Reports

Johan Nordström
Swedish Defence Research Agency
Department of C4ISR
johan.nordstrom@foi.se

Björn J E Johansson
Swedish Defence Research Agency
Department of C4ISR
bjorn.j.e.johansson@foi.se

ABSTRACT

Inter-organisational learning from exercises and response operations is crucial for improving overall response capacity for coping with cross-domain crisis events. In order to compile and disseminate experiences and acquired knowledge in the form of lessons learned, post-exercise reports are written. This paper presents a review of 17 Swedish post-exercise reports. The review was conducted with the aim to investigate whether such reports contained enough information to support inter-organisational learning, i.e. if learning goals were stated, how the event was described, method for evaluation, conclusions, and whether recommendations for change were sufficient for supporting inter-organisational learning. It was found that most reports did not support organisational development and lacked recommendations that were useful outside the own organisation or the context of the specific exercise scrutinised. The results indicate the need for an exercise evaluation framework for inter-organisational exercises.

Keywords

Crisis management, post-exercise reports, inter-organisational learning, double loop learning.

INTRODUCTION

Learning is crucial for any kind of organisation and is in some respects particularly challenging for actors in the domain of crisis management (Baroutsi, 2018; Wang, 2015). Exercise evaluation has been described as crucial for learning, as it in many cases is the only feedback given to exercise participants (Baroutsi, 2018). Inter-organisational learning from actual crisis events or inter-organisational exercises is perhaps the most challenging type of learning as this demands the identification of lessons learned that are applicable not only to specific organisations or actors, but to a collective of such organisations or actors. Exercise reports, particularly those based on inter-organisational exercise events, are consequently very important sources of knowledge that need to be disseminated within the crisis response community in order to facilitate learning about inter-organisational crisis management. In 2014, the Swedish Civil Contingencies Agency (Myndigheten för Samhällsskydd och Beredskap, MSB) published a guideline introducing the fundamentals of exercise planning (MSB, 2017a), and in 2016 the agency published a guideline on exercise evaluation (MSB, 2017b). According to MSB (2017b), the purpose of exercises is to generate knowledge of strengths and deficiencies to systematically develop or maintain the ability to handle emergencies, i.e. organisational learning. Another purpose is to test plans, actions and organisations in a simulated environment, where failures will not lead to injuries or serious consequences in the society. Post-exercise reviews should answer the questions 'how did it go?' and 'why did it happen?'. In order to do so, the exercise evaluator needs to consider the conditions for the exercise, the participants' actions and the outcome of the participants' actions (ibid.). Furthermore, MSB (2017b) recommends the use of

indicators for exercise evaluations. An indicator indicates whether a certain ability has been demonstrated during the exercise. Indicators are often defined in terms of observable data, such as questions that can be answered by true/false, or measurable data such as time, numbers or percentages.

Granåsen et al. (2018) have pointed out that a systematic approach to identifying lessons learned for inter-organisational crisis management, in other words, the crisis management *system*, is needed. In a literature review by Granåsen et al., it was found that different aspects of crisis management capability can be organised into nine thematic clusters: interaction, relationships, coordination/C2, system performance, preparedness, situation awareness, resilience, decision-making and information infrastructure. The review surveyed 150 papers that had been identified as relevant out of a total of 1197 publications found in a database search. The nine clusters identified highlight the ambiguity of what capabilities are important in inter-organisational work as well as the potentially confusing usage of terminology within the field. Nevertheless, the authors suggested that these clusters can be used to support analyses of exercise reports in the sense that lessons learned that are applicable to one or more of the identified clusters can most likely be of importance to actors.

According to Argyris (1977, p. 116), organisational learning is 'a process of detecting and correcting errors'. As emergencies are quite rare, exercises are important opportunities for detecting and correcting problems within the crisis management system. In addition, they are vital for organisational learning within the crisis management domain. Argyris (1977) denotes the cases where it is possible to detect and correct errors without changing the organisation's underlying objectives or policies as single loop learning. Cases that require a change of the organisation's objectives or policies are referred to as double loop learning. Further, Argyris (1991) argues that highly skilled professionals are very good at single loop learning but are often relatively bad at double loop learning. According to this line of reasoning, organisational change cannot be expected to take place as a consequence of everyday operations, as such operations rarely challenge established work practices. Rather, it is deviating, unusual events that challenge organisational practice and demand inter-organisational cooperation (Quarantelli, 1998; Bigley & Roberts, 2001; Trnka & Johansson, 2009). Such crisis events are fortunately rare and some organisations will only ever encounter them in exercises or simulations. This fact stresses the importance of capturing knowledge and experiences generated during such exercises in order to support both organisational and inter-organisational learning, particularly when knowledge that could support double loop learning is concerned. How is then such knowledge captured, stored and disseminated? In most cases, the main output after an exercise, be it a single-organisation exercise or an inter-organisational exercise, is a report written by an evaluator who is either internal or external to the participating organisation(s).

The objective of this study is to explore if post-exercise reports identify and describe conditions and experiences that support inter-organisational learning, i.e. is it possible to identify lessons learned, suggestions for change and action from these kinds of reports and apply it to other organisations? The study was carried out as a review of exercise reports within a Swedish context. The review investigates how regional inter-organisational exercises in Sweden have been evaluated in terms of:

- Whether the exercise reports actually describe inter-organisational aspects, i.e. do they reflect the nine thematic clusters of inter-organisational learning identified by Granåsen et al. (2018)?
- How the exercise goals and evaluation approach were described in the reviewed reports – are they suitable for inter-organisational learning or even organisational learning?
- Whether the reviewed reports support single or double loop learning as described by Argyris (1977)?
- Whether the results are applicable outside the realm of the specific exercise or organisation?
- Whether there are recommendations in the report, and to what extent these are applicable to other organisations?

METHOD

The present study is based on reviews of post-exercise reports from 17 regional cooperation exercises in Sweden during 2008-2017. The search for post-exercise reports was performed partly in a document database in MSB's integrated decision support system (RIB), and partly on the internet. The inclusion criteria were that the report must concern an exercise describing an event that in a real situation would affect several organisations, even if only one organisation participated in the reported exercise. There should thus be a potential for reporting on issues of interest in an inter-organisational context, i.e. show potential for learning about such events. Furthermore, a time limit of ten years was applied (2008), and reports were selected from what was deemed to be a representative set of counties. Due to demographical aspects, such as funding for exercises and reporting tradition/culture, some counties were found to have carried out more exercises than others. Consequently, more reports were available in those counties.

The search for post-exercise reports on the internet was carried out in two steps. In the first step, a search for 'samverkansövning' (i.e., cooperation exercise, normally indicating an inter-organisational exercise) was carried out on the web pages of all county administrative boards in Sweden. In the second step, three different searches were made using Google and the search terms 'samverkansövning' (i.e., cooperation exercise[1]), 'regional övning' (i.e., regional exercise), and 'utvärderingsrapport & övning' (i.e., evaluation report & exercise). The search in RIB generated 35 results, of which nine contained post-exercise reports that met the inclusion criteria. The internet searches yielded four additional post-exercise reports that met the inclusion criteria. As only one post-exercise report from a county with a nuclear power plant was found, one county administrative board (county 4 in Table 1) was contacted directly. Four post-exercise reports were obtained in this way. In total, exercise reports from seven of 21 counties in Sweden were included in the analysis.

All reports were written in Swedish. The exercises covered emergencies such as the release of radioactive material from nuclear power plants, heavy rainfalls, landslides, shortage of fuel, interference with payment/financial systems, pandemic flu, epizootics, large oil spills at sea, air accidents and threats of violence against schools. The reviewed post-exercise reports were written by eleven authors representing six organisations, i.e. one municipal rescue service, three county administrative boards, one university and MSB. One author, employed at MSB, wrote seven reports, one author employed at a county administrative board was a co-writer of three reports, and another author employed at a county administrative board was a co-writer of two reports (Table 1). All other authors wrote one post-exercise report each.

Table 1. Reviewed post-exercise reports

Exercise	Year	County	Author(s), employed at
1	2016	1	A, municipal rescue service
2	2017	2	B, county administrative board
3	2013	2	C, MSB
4	2010	2	D, county administrative board
5	2008	2	E, county administrative board
6	2012	3*	C, MSB
7	2017	4*	F & G, county administrative board
8	2016	4*	H & G, county administrative board
9	2016	4*	F & G, county administrative board
10	2015	4*	I, county administrative board
11	2011	5	C, MSB
12	2016	6	J, county administrative board
13	2011	7	C, MSB
14	2014	8	K, university
15	2012	8	C, MSB
16	2010	9	C, MSB
17	2008	9	C, MSB

* County with a nuclear power plant.

RESULTS

The reviewed post-exercise reports generally had the same structure: (1) background to the exercise, (2) description of the exercise scenario, (3) description of the purpose and goals for the exercise, (4) description of the evaluation process, (5) evaluation, and (6) areas for improvement. In ten of the post-exercise reports there was also a description of the exercise planning process and planning organisation (included between (1) and (2)). Two post-exercise reports lacked a description of areas for improvement.

The capability clusters identified by Granåsen et al. (2018) were applied in an effort to see what type of inter-organisational aspects the reports addressed. It was found that most reports (more than ten) addressed the clusters interaction, relationships, situation awareness, coordination/C2, preparedness, and information

[1] All translations from Swedish have been made by the authors.

infrastructure, while largely ignoring (less than ten) system performance, resilience, and decision-making. Table 2 describes the distribution of reports for each cluster. *Situation awareness* positions itself on the borderline as it occurs in nine reports, which is just about half of the reports included in this review.

Table 2. Number of reports in each cluster

Cluster	Capabilities found in post-exercise report goals or areas of improvement that are also mentioned by Granåsen et al. (2018)	Number of post-exercise reports
Interaction	Communication, collaboration, information sharing, collaboration practices, inter-organisational crisis management, participant interaction, managing collaborative actions, information flow.	16
Relationships	Formal and trust based relationships, resource allocation (shared), formal and informal networks, predictability, awareness of tasks, roles, material and personal resources, creating a collaborative culture, building a collaborative institution, organisational structure and practices.	15
Coordination/C2	Hierarchies between actors, C2 coordination, coordination centres, hierarchical multi-agency organisational structure, inter-organisational coordination, strategy.	13
System performance	Team performance, system/organisational capacity, capability and function, general organisational performance, operational efficiency.	5
Preparedness	Training and evaluation of disaster preparedness plans, contingency planning, preparedness (institutional, individual, collective, local emergency), emergency plan, learning related work activity.	15
Situation awareness	Situation assessment, shared situation awareness, situational picture.	9
Resilience		0
Decision-making	Analysis of crisis situation.	1
Information infrastructure	Information and communication technology (ICT), use of coordination technology equipment, inter-organisational IT use.	14

The main focus of the reviewed post-exercise reports was on interaction, relationships, coordination, preparedness and infrastructure. This was expected as the inclusion criteria directed the search towards inter-organisational exercises. Somewhat more surprisingly, *system performance* was noticeably absent in the goal descriptions (stated as goals in five reports), even though it was mentioned as a purpose in eleven of the exercises,. This is surprising as the overall performance of the organisation probably could be turned into an assessable indicator. *Decision-making* only occurred in one report, which may be less surprising as the focus of the identified exercises was inter-organisational cooperation, indicating that decision-making aspects probably were not the primary focus. If they were, they were probably approached from the angle of team decision-making or cooperation. *Resilience* was not found at all. However, this term is relatively new in a Swedish context, and resilience-related aspects may very well have been exercised although this terminology was not used. Information systems for supporting information sharing between organisations were rarely mentioned. The only system that was consistently referred to was WIS, an IT-system designed to support diary-like status

reports posted into a shared database. However, the post-exercise reports usually described technical difficulties with WIS rather than evaluating the potential benefits of using it. No reports provided suggestions for improving WIS. In general, the reviewed reports seem to reflect capabilities that are crucial for inter-organisational work in crisis response.

The stated goals for each reported exercise differed, although all but three stated goals that were classified as 'qualitative' in the analysis. The remaining three exercises did not report any stated goals whatsoever. No exercise was given goals that could be classified as quantitative, such as, for example, 'all fire brigades must reach the incident area within X minutes'. According to the post-exercise reports, indicators were used to evaluate the goal achievement in seven of the exercises. For each of the exercise goals, between one and 14 indicators were used for evaluation, with an average of 5.3 indicators per goal. Table 3 presents four examples of goals from two different exercises (exercise 10 and 14) that demonstrate a great difference in the number of indicators.

Table 3. Examples of goals and the number of related indicators found in the exercise reports

Exercise	Goal	Number of indicators
10	*The actors have a good ability to understand their own role in a nuclear accident*[2].	2
	The actors have a good ability to communicate internally and externally, as well as explain the decisions taken and their related consequences.	13
14	*The actors have a basic ability to work in accordance with the county's guidelines for coordination in a crisis situation.*	14
	The actors have a good C2 ability and a good ability to cooperate with other actors in: (a) search and rescue operations at sea, (b) oil spill clean-up operations at sea, (c) oil spill clean-up operations in coastal environments.	3

Table 3 also presents examples of how goals were formulated in the exercise reports. As can be seen, goals were formulated in terms of *abilities*, often related to several different situations and skills ('good ability to communicate internally and externally, as well as explain the decisions taken and their related consequences'). However, there does not seem to be a direct relationship between the complexity of the goal statement and the number of indicators used to assess whether the goals were reached. For example, the second goal in Table 3 relates to 13 indicators, while the fourth goal, the description of which is by no means less complex than the second goal, only relates to three indicators. In turn, indicators manifest themselves in different ways in different reports. Table 4 shows four randomly selected goals from the various reports and how the indicators were described. As can be seen, most indicators were defined as observable events that can be answered by *yes* or *no*.

[2] All citations and examples from exercise reports have been translated from Swedish by the authors.

Table 4. Examples of indicators for different exercise goals

Exercise	Goal	Indicators
2	*Achieve reporting of operational picture and a shared situational awareness*	• Requested information is delivered to the county administrative board within the stipulated time. • Requested documentation is delivered to the county administrative board with the requested information. • WIS (an MSB system used for information sharing on the internet) is used among actors as a tool for reporting operational picture. • A shared situational awareness is created between the involved actors during orientation and coordination meetings, using the regional methodology for achieving a shared situational awareness. • The shared situational awareness provides sufficient support for orientation and coordination on a regional level.
3	*Basic ability to cooperate according to the regional cooperation agreement.*	• If necessary, the regional TIB group ('officials on standby group') is contacted by the alarm centre within 30 minutes. • If necessary, a first orientation and coordination meeting is held within one hour after the first alarm. • Within two hours, the TIB group has made a decision on the continued orientation and coordination of the actions taken due to the event.
7	*The county administrative board has a basic ability to provide relevant means of communication at the forward command post*	• There is access to Rakel (a TETRA-based Swedish communication system) and it can be used. • There is access to Skype and it can be used. • It is possible to connect to the county administrative boards' intranet.
14	*Basic ability to cooperate based on local and regional oil spill response plans in the event of a major oil spill at sea.*	• The actors assess the need for support from other organisations. • The actors formulate the need for support from other actors. • The actors request support from other actors. • The actors receive a response to their request for support from other actors.

As can be seen in Table 4, some indicators, for example 'There is access to Rakel (a TETRA-based Swedish communication system) and it can be used' is relatively easy to assess. Others, such as 'A shared situational awareness is created during orientation and coordination meetings between the involved actors, using the regional methodology for achieving a shared situational awareness', can be very challenging to assess, if at all possible. In terms of evaluation methods, various qualitative methods, such as interviews, observations, evaluator judgement, surveys, protocols, and after-action reviews were applied. Interestingly, all but one report stated that methods were combined in different ways to evaluate the concerned exercise. Applied in twelve of

the evaluations, surveys were by far the most common method used. . However, surveys were in all cases combined with other methods, most commonly observations and evaluator assessments. In three cases, interviews were utilised. 'Evaluation seminars', probably resembling after-action reviews, were relatively common, with five occurrences in our data set. The least common method was 'protocols', which evidently was a form of pre-arranged checklists used to assess whether or not the participants in the exercise reached the specified goals.

Table 5. Goal type, evaluation methods, and use of indicators identified in the reviewed reports.

Exercise	Type of Goals	Methods applied	Use of Indicators
1	Qualitative	Evaluator's rating, Documents and logs from the exercise, Observations, Evaluation seminar.	No
2	Qualitative	Evaluator's rating, Observations, Documents and logs from the exercise, Evaluation seminar.	Yes
3	Qualitative	Survey, Evaluator's rating, Review of documentation and logs from the exercise, Evaluation seminar, Observations.	Yes
4	Qualitative	Evaluator's rating, Survey	No
5	Qualitative	Observations based on Observation protocols, Review of documentation and logs from the exercise, Evaluation seminar, Survey, Interviews.	No
6	Qualitative	Reports from evaluators, Evaluation seminar	Yes
7	Qualitative	Evaluator's rating, Survey, Evaluation seminar.	Yes
8	No goals	Survey, Observations.	No
9	No goals	Survey, Documentation from exercise	No
10	Qualitative	Survey, Evaluator rating based on Observation Protocol, Evaluator's rating.	Yes
11	Qualitative	Survey, Evaluator's rating, Observations, Review of documentation and logs from the exercise, Evaluation seminar	No
12	Qualitative	Survey, Review of documentation and logs from the exercise, Evaluator's rating, Observations	Yes
13	Qualitative	Survey, Evaluator's rating, Review of documentation and logs from the exercise, Evaluation seminar.	No
14	Qualitative	Surveys, Evaluator's rating, Interviews	Yes
15	No goals	Survey, Observations	No
16	Qualitative	Survey, Review of documentation and logs from the exercise, Observations, Interviews.	No
17	Qualitative	Documentation and logs from the exercise, Survey	No

The outcome of these evaluations were in all cases descriptive, independent of whether goals were articulated and/or indicators were used. No statistical or other form of numerical analysis was conducted in order to

compare the outcome of the exercise with set goals, earlier exercises, or other exercises.

However, the results were discussed in a variety of ways. Six evaluations discussed whether or not the exercise goals were fulfilled. Three discussed the strengths and weaknesses of the exercise. One presented lessons learned. The other evaluations discussed the participants' experiences, whether or not the design of the exercise was appropriate, the number of participants in the surveys conducted, etc.

Based on the outcome of our analysis, an effort was made to determine whether or not the exercise reports could be considered to support double loop learning, as described by Argyris (1977). It was found that only five reports seemed to achieve this goal (Table 6). This analysis was based on the following criteria: Reports were deemed to support single loop learning if the recommendations focused on improving existing procedures, structures or functions, such as exercising more to perfect a procedure, improve individual skill, or improve an existing technical system. Reports were deemed to support double loop learning if the report questions revolved around the way work was conducted, and if there were recommendations going beyond conclusions in the style of 'more exercises are needed', or other suggestions that can be labelled as single loop learning. The type(s) of goal(s) formulated for each exercise was also taken into account. Table 6 illustrates the number of reviewed reports that support single loop learning vs. double loop learning.

	Type of learning	
	Single loop	Double loop
Indicators used for evaluation	6	1
Indicators not used for evaluation	6	4

Lastly, we performed an analysis of the recommendations provided in the reviewed reports in an effort to answer the question whether the reports support learning outside the specific exercise context. Eight of 17 reports did to some extent support learning outside the own organisation or specific exercise context. In some cases, the recommendations require a degree of interpretation on behalf of the reader to achieve this. In general, recommendations may be hard to implement even within the realms of the own organisation or exercise context. Table 7 presents a set of randomly selected suggestions for improvements from different reports. As shown, some of the recommendations were written in such a way that they include a motivation as well as suggestions on how to implement the recommendation. In other cases, the recommendation consists of a few words, which implies that readers need to provide a context as well as a way to implement the suggested recommendation themselves. It can also be concluded that there seems to be no agreed format for providing recommendations in post-exercise reports of the kind reviewed in this paper.

Table 7. Random examples of conclusions/future improvements in the post-exercise reports

Exercise	**Conclusion/suggested future improvements**
2	*One of the goals with the exercise was to achieve a shared situational awareness. Today, there is a defined method for achieving a shared situational awareness. Simplified, the method is based on all actors providing information, which is then compiled into a regional shared operational picture. During the exercise the information was distributed by the WIS system, except for restricted information. As there was a new version of WIS, which was not fully functional during the whole exercise, problems occurred with both the submission of information and the compilation of a common operational picture* • *Further development work should be carried out based on the established method. This work should highlight information gathering, compilation, updates and dissemination of the common operational picture. Knowledge about and the ability to use WIS is important. The work should include routines for both the regular approach and for a backup system in case the regular system fails. It is also important to highlight how restricted information is to be handled and distributed.*
3	*Develop the work on shared situational awareness by:* • *Determining what information shared situational awareness*

	should include. • *Providing procedures for reporting.*
6	*The following points need to be addressed to increase the county's ability to handle a nuclear accident:* • *Confusion about concepts* • *Clarification of roles, responsibilities and mandate* • *Communication with units at sea* • *Alarm numbers and messages* • *Receiving stations* • *Synchronisation of plans* • *Transport issues and traffic diversion* • *Endurance* • *Development of exchanges of liaison officers* • *Increase of the ability to command county administrative board staff.*
17	*The three closing questions in the questionnaire discussed the future. Some answers that stood out are reported below.* ***Have you discovered a need for constitutional changes to better manage a pandemic? If so, please specify.*** • *The Working Hours Act may constitute an obstacle. A review of possible exceptions from the act is needed.* • *A legal prerequisite for distributing fuel or taking action with mandates similar to those of an incident commander, according to the Civil Protection Act (SFS 2003:778,) is needed* ***What support does your organisation expect from the county administrative board for the continued planning for pandemics?*** • *A handbook on the legal aspects of crisis management.* • *Exchange of experiences from the planning process within the county.* • *Epidemic intelligence and exercises.* ***What support does your organisation expect from other actors than the county administrative board for the continued planning for pandemics?*** • *Support from the Swedish Institute for Infectious Disease Control in the production of instructions and advice for contingency planning.* • *Knowledge from the county council's infection protection unit.*

In general, the exercise reports focused on describing what happened and what actions were carried out during the exercise. Only a small number of the reports were devoted to analysing the problems that arose during the exercise, i.e. finding the underlying reasons for the problems that occurred, how the problems were solved during the exercise, and what measures that need to be taken to prevent the problems from occurring again. It is also difficult to follow the link between the problems that arose during the exercise and the suggested improvements.

Naturally, the evaluation of the exercise took its starting point in the goals of the exercise. However, as most of the exercise goals were formulated as abilities, there is not much in the way of analysis, and there are only a few suggested improvements in the cases where the exercise goals were met, even if the evaluation showed that

there was room for improvement.

DISCUSSION

When analysing the 17 reports in the light of the nine thematic capability clusters identified by Granåsen et al. (2018), it was shown that the reports largely reflect capabilities important to inter-organisational crisis response work. This is promising as the thematic clusters reflect a large set of academic writings on inter-organisational work, and thus indicate that the core of the exercises were conducted in such a way that there was potential for learning and improving overarching crisis response system capabilities. However, some challenges and room for improvement remain, as suggested by the results presented above.

The 'indicator approach' suggested in the MSB (2017b) guidelines is positive in the sense that indicators, at least in some respects, can be assessed objectively and with well-defined measures, such as time, distance, frequency, etc. However, the connection between indicators and theory in terms of learning, particularly organisational and inter-organisational learning, is weak, even in a best-case scenario. Hollnagel (1997) discussed that researchers and evaluators often grasp for *what is measurable* rather than *what should be measured*. This implies that many of the measures performed using the MSB guidelines may capture experiences that are less useful for supporting aspects of double loop learning, or even single loop learning. In several cases, indicators of the type 'was IT-system X used during the exercise? ' were found. Even if it is possible to count the number of times IT-system X was used or not, such an indicator, nor reporting the outcome of it, does not explain *why* it was/wasn't used. Furthermore, the present review shows that the type of indicators used vary greatly between similar goal formulations, indicating that the theoretical or methodological support for assigning indicators is poor. A plausible hypothesis is that the number of indicators for a given goal reflects the possibility to identify observable events rather than a reflection of the complexity of the goal. Some goals are related to only two indicators, whereas others are related to as many as 15. In addition, the descriptions of the various indicators suggest that there is a great variation in the types of method needed to assess whether they have been fulfilled or not, ranging from system log files to subjective self-estimates. This is not a problem in itself, but reflects the ambiguity in the way indicators are chosen and applied in exercises.

The present review showed that when indicators were used to evaluate an exercise, the focus for the evaluation tended to be on whether the goals of the exercise had been met or not. However, as most exercise goals focused on ability and not learning, the result of the evaluation tended to present a 'test result', rather than a starting point for future improvements of the crisis management system. This view indicates that the exercise was viewed as a confirmation of the quality of an existing ability, rather than a learning event. The level of detail in indicators and goals also varied greatly, ranging from the ability to handle a specific IT-system to more generic abilities to establish inter-organisational cooperation. This variety of indicators and goals suggests that challenges remain when it comes to creating guidelines and training for exercise planners and evaluators, if useful exercise reports in an inter-organisational context are to be assured.

Another aspect of the evaluation in the reviewed reports was the descriptive, qualitative, approach utilised. While a qualitative approach is useful for describing what took place during the exercise and why, it has limited value in terms of comparability between different exercises. For example, if no quantitative performance assessment is carried out it becomes impossible to analyse the development of performance over time. The same goes for comparisons between exercises or organisations. In sum, all kinds of statistical analysis are effectively rendered impossible.

Moreover, support of double loop learning was found in fewer post-exercise reports using indicators than in post-exercise reports where indicators had not been used. In the single case where a post-exercise report used indicators and the report resulted in double-loop learning, the double loop learning was supported by reports by observers rather than evaluation reports based on indicators from evaluators. Clear ways for incorporating double loop learning aspects in exercises, as well as methodological support for evaluating and reporting this, seems to be lacking or be outside the scope of most regional exercise evaluators' training.

The challenges posed by crisis events today also point to a more overarching question: given that most exercises aim to improve existing capacities or assure that abilities are kept on an acceptable or good level, will crisis management systems be able to handle increasingly complex and challenging events? The literature shows that crisis response organisations always need to prepare for extraordinary events, suggesting that such organisations need to be able to perform not only at an acceptable level but at an *exceptional level*. Consequently, this needs to be reflected in exercise goals, at least in some cases. This implies that failure during exercises must be a possibility, something that was noticeably absent in the reviewed reports.

Only about half of the reviewed reports contained recommendations that were found to be useful outside the context and the organisations taking part in each respective exercise. However, it should be noted that the

recommendations identified frequently require a fair degree of interpretation on behalf of the reader as they do not always motivate why the recommendation is given or how the recommendation should be implemented. It is naturally challenging to create such recommendations, particularly in an inter-organisational context, but our review shows that there is a need to investigate if it is possible to create a method or guideline concerning the format of such recommendations as they are crucial for knowledge sharing in an inter-organisational crisis response context. One suggestion could be to organise the lessons learned from an exercise according to the nine clusters suggested by Granåsen et al. (2018) and provide recommendations for each cluster in a structured way.

How should exercise reports then be improved to better support inter-organisational learning? The answer is multi-faceted and cannot be answered based on this investigation alone. However, some suggestions can be made based on the outcome of this study. Firstly, there is a lack of common terminology that could be supported by creating an inter-organisational ontology that describes phenomena that are important for inter-organisational exercises. Such an ontology could be based on the clusters provided in the paper by Granåsen et al. (2018). Secondly, the way data is collected during exercises must be aligned in such a way that it is possible to compare different exercise events with each other. Exercise evaluators should have similar training and be supported by a data collection framework, including observation protocols and other data collection tools. Similar indicators should be used across different exercises. All exercises cannot be treated in the exact same way when it comes to evaluation, but a small set of approaches to evaluation should be sufficient to cover most situations. Thirdly, exercise reports should have a similar structure and disposition, making it easy for readers to find the sections they are most interested in. Conclusions should preferably be arranged in the same way. Recommendations that apply to both immediate needs (single loop learning) and more fundamental challenges (double loop learning) should be given.

One way of supporting the effort to improve data collection during exercises, as well as the task of writing useful post-exercise reports, could be to introduce an IT support system that structures the exercise evaluators' work . Such an IT-system should preferably be possible to carry around, like a tablet, be connected to a database for storing and sharing exercise data between participating organisations in the inter-organisational context, and have the ability to record sounds and videos. The physical device needs to be rugged and have enough battery capacity to endure the realities of field observations. Essentially, the exercise evaluation support system should be a digital notepad, using semi-structured observation protocols and having the ability to document different situations that the exercise evaluator finds important. The database capturing the collected data should provide output that is structured according to the logic of the inter-organisational exercise reports suggested in the previous paragraph. This does not imply that analysis should be automated, only that a structured approach to data collection is supported and that a shared format for collecting the same data is assured.

CONCLUSIONS

This review has identified a number of challenges for knowledge sharing from exercises in an inter-organisational context. In the analysis, it was found that:

- Exercise goals are in many cases formulated as 'abilities', indicating that exercise goals focus on assuring that the involved organisations have the ability to perform certain tasks, rather than relating to learning or development.
- The type and number of indicators used to assess the exercise goals vary greatly between exercises. In many cases, the indicators concern specificand easily assessable issues, such as 'was system X used?', without a clear description explaining why this is important or how it should be interpreted in an inter-organisational context. Theoretical support for the selection and usage of indicators was largely absent in the reviewed reports. In addition, there were no discussions about whether the indicator(s) used were sufficient to determine if a specific goal had been met.
- No structured data collection of quantitative measures was applied in the reviewed exercise evaluations. Neither were statistical analyses performed on the collected data. This limits the possibility to assess development over time, as well as the possibility to compare exercise outcomes or organisational performance between exercises.
- Five of 17 reports could be viewed as supporting double loop learning, i.e. supporting recommendations that could lead to change on a systems level, such as process, organisation, training or method. However, these recommendations did in most cases lack sufficient motivation and description of how such a change should take place.
- About 50% of the reports were deemed to have the potential to be useful in other contexts than that of the specific exercise or involved organisation(s). However, as in the case with double loop learning, the

recommendations and lessons learned generally did not provide suggestions on how to implement them in other contexts than the reported exercise.

- With the exception of one nuclear energy emergency exercise where an 'internet diary' was used to share information between the actors, WIS was the only IT system for information sharing mentioned in the post-exercise reports. Regarding the use of WIS, conclusions in the post-exercise reports were limited to the need for education and training of individual users, and the need for routines concerning how the system should be used for sharing an operational picture. None of the examined post-exercise report suggested technical improvements to WIS, despite the fact that several reports mentioned that there are deficiencies in the system and that users experience difficulties when using the system.

An investigation is needed in order to formulate a framework that supports planners and evaluators of inter-organisational exercises in conducting exercises and evaluations that are useful, not only for the exercised participants/organisations, but also for other actors. The authors of the present study therefore suggest an outline for such a framework based on the clusters identified by Granåsen et al. (2018). This should include training provided to all inter-organisational exercise evaluators, and be supported by a rugged, field-worthy IT system, such as a tablet, that aligns data collection by providing observation protocols and the ability to collect sound and video recordings. Inter-organisational crisis response capabilities are crucial, but training and exercising such capabilities is costly and resource-demanding. It is therefore highly important to ensure that experiences and lessons learned from such exercise events can be utilised to their full extent. In most cases, the primary product capturing lessons learned from an exercise is the post-exercise report, which thus must be written in such a way that it is relevant beyond the scope of the specific exercise or organisations involved, and include recommendations that are useful for a wide range of actors in the crisis response community.

ACKNOWLEDGEMENTS

This paper presents a study carried out within the research project KOMET, sponsored by the Swedish Civil Contingencies Agency.

REFERENCES

Argyris, C. (1977) Double loop learning in organizations, *Harvard business review*, 55, 5, 115-125.

Argyris, C. (1991) Teaching Smart People How to Learn, *Harvard business review*, 69, 99-109.

Baroutsi, N. (2018) A Practitioners Guide for C2 Evaluations: Quantitative Measurements of Performance and Effectiveness. In *Proceedings of the 15th ISCRAM Conference*, Rochester, NY.

Bigley, G.A., & Roberts, K.H. (2001) The incident command system: High-reliability organizing for complex and volatile task environments. *Academy of Management Journal,* 44, 6, 1281-1299.

Granåsen, M., Olsén, M. & Oskarsson, P.-A. (2018) Assessing Inter-organizational Crisis Management Capability - Initial Results of a Systematic Literature Review, *Proceedings of the 15th ISCRAM Conference*, Rochester, NY.

Hollnagel, E. (1997) Measurements and models, models and measurements: You can't have one without the other. *Collaborative crew performance in complex operational systems,* 14, 2.

MSB. (2017a) *Exercise guidance: basic manual - an Introduction to the fundamentals of exercise planning*, Swedish Civil Contingencies Agency, Stockholm.

MSB. (2017b) *Exercise guidance: method booklet - exercise evaluation*, Swedish Civil Contingencies Agency, Stockholm.

Quarantelli, E.L. (1988) Disaster Crisis Management: A summary of research findings. *Journal of Management Studies*. 25, 4, 373-385.

Trnka, J., & Johansson, B. (2009) Collaborative Command and Control Practice: Adaptation, Self-Regulation and Supporting Behavior. *Int. J. Information Systems for Crisis Response and Management*, 1,2, 47-67.

Wang, W. T. (2015) Evaluating organisational performance during crises: A multi-dimensional framework, *Total Quality Management*, 23, 6, 673–688.

Opportunistic Affiliation in Spontaneous Volunteer Management

Daniel Auferbauer
AIT Austrian Institute of Technology
Daniel.Auferbauer@ait.ac.at

Roman Ganhör
TU Wien
Roman.Ganhoer@tuwien.ac.at

Hilda Tellioğlu
TU Wien
Hilda.Tellioglu @tuwien.ac.at

ABSTRACT

Spontaneous volunteers influence crisis and disaster relief efforts as both an effective aid and a stressing factor for emergency organisations. Managing the negative impacts of spontaneous volunteering has thus become part of command and control deliberations. In this paper, we take a closer look at integrating spontaneous volunteers into the formal response system to mitigate negative impacts. Working with participants from formal response organisations, we gathered qualitative data regarding the management of spontaneous volunteers during the European migration crisis in 2015. Through thematic analysis, we extracted topics to systematically describe the interaction between emergency organisations and spontaneous volunteers. As implication thereof, we propose how computer supported systems can be applied to better manage spontaneous volunteers. In our discussion, we focus on the registration process and *ad hoc* verification of spontaneous volunteers to better integrate them in the formal response process.

Keywords

Crisis and disaster management, spontaneous volunteers, command and control, volunteer management

INTRODUCTION

Volunteers have a considerable impact in Crisis and Disaster Management (CDM), which is particularly true for spontaneous volunteers. Spontaneous volunteers have no affiliation to formal organisations and participate to address sudden, urgent needs. The nature of their role, and whether their activity should be supported or suppressed, is subject to debate. On the one side, proponents of a top-down approach, leaning towards the command and control paradigm, at times consider spontaneous volunteers a hindrance or nuisance (Cone et al., 2003; Sauer et al., 2014; Whittaker et al., 2015). On the other side, spontaneous volunteers are often the first, and a very important, form of relief in the immediate aftermath of an incident (auf der Heide, 2003; Twigg and Mosel, 2017; Whittaker et al., 2015). Whatever side one may prefer, research has shown that the appearance and convergence of spontaneous volunteers at the disaster site can have negative side effects for organised relief efforts (Dynes, 1994b; Fritz and Mathewson, 1957; Sauer et al., 2014). As the presence of spontaneous volunteers is a common aspect of CDM (auf der Heide, 2003; Drabek and McEntire, 2003; Twigg and Mosel, 2017; Whittaker et al., 2015), response efforts should incorporate spontaneous volunteers in their decision making (Barsky et al., 2007). However, the rather static and bureaucratic command and control model is not well suited for spontaneous and loosely organised relief efforts (Drabek and McEntire, 2003) and needs adaptions to lessen negative effects of spontaneous volunteering while strengthening their problem-solving capabilities.

In this paper, we present the results of our research on the necessity and nature of adaptions to the command and control model, to better accommodate spontaneous volunteers. These results were abducted through thematic analysis on qualitative research data: interviews and group discussions were conducted in the context of the European migration crisis in 2015. The contribution of our work is the systematic description of four distinct dynamics that affect spontaneous volunteer management. Further, we describe and discuss possible technological approaches implicated by these dynamics.

RELATED WORK: CIVIL SOCIETY IN CRISIS AND DISASTER RELIEF

The importance of citizens' initiative in relief work, especially in the early phase, has been emphasized repeatedly, starting with one of the earliest works in disaster sociology (auf der Heide, 2003; Dynes, 1994b; Helsloot and Ruitenberg, 2004; Prince, 1920; Twigg and Mosel, 2017; Whittaker et al., 2015). However, from the perspective of formal organisations for crises and disaster relief such initiatives are not always seen positive, as they are hard to control and difficult to plan for (Sauer et al., 2014; Skar et al., 2016). Formal organisations have previously been reported to primarily follow procedures aimed at establishing order after the chaos of a crisis or disaster (Dynes, 1994a). Yet research does not support the need to control antisocial and destructive behaviour in the face of a crisis (Drabek and McEntire, 2003; Helsloot and Ruitenberg, 2004). On the contrary, researchers have considered informal activities essential for effective, if not necessarily efficient, relief (Dynes, 1994b). This creates a situation where civil society provides the required resources, yet in a form of response that is inefficient (Dynes, 1994b). Harris et al. (2017) describe the role of spontaneous volunteers as *paradoxical*, in that they are simultaneously needed and not wanted by crisis managers. This conflicting situation results in a need to manage the activities of citizens in a way that reduces inefficiency, while allowing flexibility.

Spontaneous Volunteers and Convergence

Formal organisations in CDM use the term *volunteer* primarily to describe persons that contribute through predetermined structures of an official response body (Whittaker et al., 2015). This definition makes volunteers part of the formal response system, where they act in accordance with established procedures. Through regular service volunteers get socialised in the field of CDM. This form of volunteerism is traditionally popular in Central Europe and Scandinavia with levels of participation in voluntary or charitable organisations regularly exceeding 50% of the population, reaching 67% in Norway (Plagnol and Huppert, 2010). Britton (1991) refers to such organised and affiliated volunteers as *permanent disaster volunteers*.

A trend contrary to permanent disaster volunteers has been noted at the turn of the century: volunteering 'decreasingly corresponds to strong identification and long-lasting membership' with organisations (Hustinx and Lammertyn, 2003). Indeed, there has been a noticeable number of publications addressing volunteers that contribute to disaster relief without joining an official response organisation. Various terms have been used for such participation, including: *informal* (Whittaker et al., 2015), *unaffiliated* (Barsky et al., 2007; Zettl et al., 2017), *episodic* (Hyde et al., 2014; Starbird and Palen, 2013), *freelancing* (Cone et al., 2003) or *spontaneous* (Harris et al., 2017; Sauer et al., 2014; Simsa et al., 2018; Twigg and Mosel, 2017). While these terms are not mutually exchangeable, they all describe volunteers who are active outside the formal response system; even though they occasionally are integrated into formal efforts (Scanlon et al., 2014). Spontaneous volunteers (as we refer to them in this paper), who may lack both training and equipment, pose an issue for official response organisations, as they may endanger their own health and disrupt organised response (Whittaker et al., 2015).

One phenomenon of spontaneous volunteering is *convergence*: the physical movement of persons or material towards the disaster site, as well as the transmission of information and requests towards communication centres of a disaster site (Fritz and Mathewson, 1957). In our research, we are primarily interested in the convergence of persons[1]. Spontaneous volunteers are motivated to render aid and offer support, and so they will mobilise and move to the incident site (Dynes, 1994b). This individual and unorganised mobilisation can cause congestions of persons and vehicles, posing an additional logistical challenge for official crisis management (Drabek and McEntire, 2003). Convergers may 'overrun' local infrastructure (Fritz and Mathewson, 1957), deplete resources (Cone et al., 2003) or overwhelm those trying to coordinate response (Drabek and McEntire, 2003). An over-abundance of helpers in the disaster area may even engender more victims (Dynes, 1994b). Emergency and relief organisations have adopted concepts to address personal and material convergence. Examples are the Volunteer Reception Center of the US Federal Emergency Management Agency or the Operations Coordination Centre, employed by the United Nations Office for the Coordination of Humanitarian Affairs. Both are concepts intended to cover the reception of individuals or whole organisations, respectively. While (some) organisations have procedures at hand to handle physical convergence, Waldman and Kaminska (2015) propose virtual reception centres, which could yield benefits for both volunteers and formal relief organisations. However, little literature is available on digitalisation of volunteer reception on site.

If spontaneous volunteers' convergence on a disaster site is inevitable, then their participation in relief efforts

[1] The convergence of goods and information impose their own. separate problems; relating to supply chain management and information management, respectively. Even 'official' convergence is problematic (Dynes, 1994b; Fritz and Mathewson, 1957).

should be actively managed – to prevent injury or damage, to reduce disruption of organised response, and to increase effectiveness of CDM (Sauer et al., 2014; Whittaker et al., 2015).

Efforts of Civil Society during the Migration Crisis in Austria

September 4th, 2015, saw the beginning of the 'March of Hope', which heralded the height of the migration crisis for Central Europe: over 500 people, on their way westwards to seek refuge, broke their immobilisation near Budapest's main train station by proceeding on foot towards Austria (Kallius et al., 2016; Kornberger et al., 2018). This led the Austrian state to open its borders. Subsequently, efforts of the civil society played an essential role in providing aid and shelter for newly arriving migrants, thereby averting a humanitarian catastrophe (Simsa, 2017). A lack of response from state institutions prompted collective action of citizens – for example, humanitarian relief at Vienna's main train station was operated by a volunteer movement that had not existed before (Kornberger et al., 2018). This was a highly visible, if just one of many, examples of citizen activism to cope with the influx of refugee seekers. Approximately 300,000 would cross the borders of Austria (population 8.7 million) until the end of the year, posing a continuous humanitarian and logistical challenge (Kornberger et al., 2018).

METHODOLOGY: STUDY

This study was set up immediately following the extensive efforts of civil society during the migration crisis in 2015. We investigate the following research questions from the viewpoint of the formal crisis response system:

RQ1 How was the spontaneous volunteer effort during the recent migration crisis perceived by representatives of the formal response system?

RQ2 What organisational structures, measures, or tools were in place to integrate spontaneous volunteers into formal relief efforts?

RQ3 What were the obstacles encountered in the integration of spontaneous volunteers into formal relief efforts, if any?

To address these questions, we conducted two group discussions and two complementary interviews. Both group discussions were held with representatives of formal organisations that provided disaster relief as part of their ongoing work. Interview partners were representatives from public agencies, mediating between formal organisations and volunteers. The participants and their referential identifications are given in Table 1.

Affiliation	Participants	Method	Denotation
Formal relief organisation	CDM professionals from tactical and operational levels who worked with volunteers over the course of the migration crisis.	Group discussion	*<f-1>…<f-6>*
Mediation agency	Persons in leading roles who work to conciliate formal organisation's open volunteer positions and citizens who want to become active as volunteers	Semi-structured interviews	*<m-1>,<m-2>*

Table 1. Study participants

While group discussions examined the challenges that the formal response system experienced in the involvement of untrained citizens, the interviews investigated mediating agencies and how the crisis changed their work routines. Group discussions and interviews were of semi-structured nature. Detailed questions and guidelines were prepared in accordance with our research questions. However, participants were encouraged to speak freely and were allowed to deviate from the original topic to some degree.

The group discussions and interviews yielded a total of 6.2 hours of audio data. This audio data was transcribed entirely; forming our data set. Eventually, we conducted a thematic analysis (Braun and Clarke, 2006) on this data set. This approach was abductive, i.e., the themes were derived from the data (as opposed to fitting data into pre-existing themes). Coding of the data set was done according to our research questions. Encoded text passages constituted our initial data items. Data items were arranged into *topics* on a semantic level; an exemplary topic is the collection of data items addressing the use of pen and paper to register volunteers on site. Topics can exhibit a high level of inter-connectedness, forming over-arching *themes*. Identifying and describing these themes was the first analytic step not directly based on the original data set.

As themes became entangled with each other, adaptions were needed to disentangle them, while asserting their grounding in the original data set. Some themes were discarded for lack of proper grounding in the original data

set, others were merged or split to account for internal variances or contradictions of existing and emerging themes. For our analysis, themes provide both a layer of abstraction from original data and a lens through which to view and interpret topics and data items. Thus, the analysis process becomes iterative: as we discover new themes in the original data set, we can look at and interpret previously identified topics and themes from a different perspective. Sometimes this led to adaptions of existing themes. We reiterated this process until individual themes were sufficiently distinct from each other.

Our themes captured organisational and technological aspects of the interaction between volunteers and formal organisations. Themes held answers to our research questions, but did not offer a satisfactory amount of insight about their effect on relief efforts. We introduced the concept of a *dynamic view* to help us derive implications that our themes have; implications for the integration of spontaneous volunteers as an effort by command and control to conduct efficient relief. The dynamic view offers a new lense on our analysis, by asking how each theme affects relief efforts. We ensure a continued relation to our research questions by not changing the themes themselves, but aggregating them based on their meaning for the integration of spontaneous volunteers.

ANALYSIS RESULTS: DYNAMICS OF INTERACTION

Figure 1 is intended to guide the reader through our work via four dynamics (elements III, IV, V and VI). They will form the basis of discussing eventual technological support (elements A and B). The dynamics are rooted in a perceived need to contribute (element I) and affect the efficiency of relief efforts (element VII).

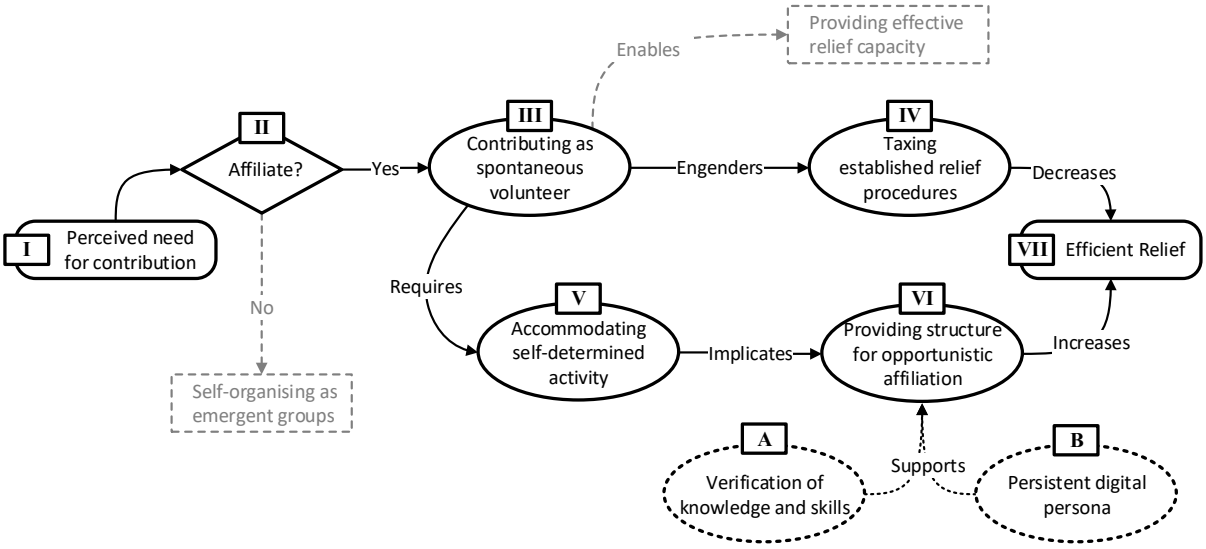


Figure 1. Dynamic view of interactions between spontaneous volunteers and emergency organisations

Motivation to Volunteer (Figure 1, I)

Volunteers in CDM are, per definition (Plagnol and Huppert, 2010; Whittaker et al., 2015), conducting relief efforts of their own free will, without coercion. Thus, their motivation must be intrinsic, i.e., be the result of their own initiative. The actuator, purported by literature (Dynes, 1994b; Lowe and Fothergill, 2003) and affirmed within our own data, is the perception of a need for one's own contribution – to 'do something'. The focus of this paper is on spontaneous volunteers (who are not affiliated with any formal organisation), in contrast to affiliated volunteers (who have registered with a formal organisation).

Becoming a Spontaneous Volunteer (Figure 1, II)

After a volunteer perceives a need for contribution and decides to 'do something', we make a distinction between two forms of volunteer activity. This was articulated by representatives of formal relief organisations in our own data.

> *Like spontaneous volunteers that came to [incident site] and said, 'I have two good hands, put me to work where you need me'. That's a different approach than going 'I drive over there with some soup and then I'll decide where to distribute it, without coordinating'. In my opinion, those are two different demographics. (<f-4>)*

Does a citizen become a volunteer, approach a formal organisation for guidance, or even for orders, or does s/he pursue activities of his or her own choice? Deciding for the latter, for whatever reason[2], entails a whole different set of problems, which exceeds the scope of this paper. Instead, we focus on citizens that intend to approach formal organisations, at least for guidance in their efforts, if not outright tasks or orders.

Contributing as Spontaneous Volunteer (Figure 1, III)

Spontaneous volunteers contrast affiliated volunteers (Whittaker et al., 2015) or permanent disaster volunteers (Britton, 1991) in three aspects, as far as our own data is concerned. Firstly, the volunteer decides time and place of their contribution. <*f-1*> recalls that many volunteers chose to participate for a limited time on very short-term notice; giving the example of someone showing up to help for two hours because they missed their train.

Secondly, a 'project-related' <*f-1, f-5*> form of volunteering, whereby volunteers choose the circumstances of their contribution, instead of entering a long-term affiliation with an organisation. <*f-1*> notes how 'the classical volunteer' will disappear over the next decades, while project-related engagement will rise – a trend they increasingly noted during the migration crisis. <*f-5*> concurs by stressing the difficulties in dealing with it.

> *This realisation that you [<f-1>] mentioned, that there are more project-based volunteers, is also noticeable for us and now there is this reflection: how do you handle that, how can you integrate that reasonably? (<f-5>)*

Thirdly, confirming previous research by Hustinx and Lammertyn (2003), <*f-5*> states how project-oriented volunteers often relate less to the organisation that provides the frame for their activity:

> *There are many volunteers at work in [relief organisation's] facilities that have basically no relatedness to [relief organisation]. Indeed, it was the case that some people, primarily with migratory background, who worked as translators, told me they never heard of [relief organisation], asking me what that is and if it's a new thing. (<f-5>)*

It stands to reason that the migratory background of volunteers was the reason they never heard of that specific relief organisation. The point, however, is that, in line with the more transitory nature of participation, volunteers may pay less attention to which organisations provides the frame for their contributions. Overall, data gathered from representatives of the formal response system suggest that there is a decreasing socialisation of volunteers in the emergency system.

Taxing Established Relief Procedures (Figure 1, IV)

Spontaneous action of individuals may lead to stress in the formal response system, decreasing relief efficiency through increased administrative overhead or contravening other efforts by unfocused action (Figure 1, IV → VII). Without guidance or information concerning the overall operational picture, spontaneous volunteers may inadvertently undertake actions that contravene other relief efforts (<*f-6, m-2*>). This includes the donation of commodities, the handling of which binds further resources (<*m-2*>). Lack of guidance may be caused by shortage of commanding personnel as well as unawareness (<*f-1, f-3, m-2*>) or unwillingness (<*f-2*>) of volunteers to integrate into command and control structures. A second stressor stems from the administrative overhead when registering newly arriving spontaneous volunteers. Formal organisations require volunteers-to-be to formally register for legal coverage and insurance. This is done mostly on premise, using pen and paper (<*f-1, f-2, f-4*>), binding resources at various levels.

To mitigate the stress of spontaneous volunteer participation, programmes for pre-registration of volunteers had previously been established and technological support attempted, c.f. (Auferbauer et al., 2015, 2016). <*f-1*> states that the purpose of such pre-registration, then, was to not have spontaneous volunteers on site, yet the situation was different during the migration crisis:

> *You couldn't put people to good use if they just showed up then, because they caused more trouble than they were helping. […] But that is different now, because now we need people who come [to shelters] directly. […] Today, in running operations, when someone comes over, they are welcomed and invited to start immediately (<f-1>)*

[2] Including: dissent regarding the objectives set or the way they are to be achieved; a lack of presence of visibility of formal organisations; or personal preference to work apart from hierarchical structures.

It appears that volunteers who were already enrolled in the organisation's volunteer programme (i.e., pre-registered volunteers) also queried information in advance; to be briefed where to go and whom to report to (*<f-2, f-4>*). This indicates that even pre-registered volunteers will not necessarily wait for orders and can be part of unwanted convergence.

Accommodating Spontaneous Participation (Figure 1, V)

Formal relief organisations try to accommodate spontaneous participation through their existing organisational structures. Yet sometimes the volume of participation outgrows the expansion capacity of these structures:

> *<f-4>:I hope [regional command] drew experience from this. That we need to educate and train more people for leadership positions.*
> *<f-3>: Yes, those were lacking-*
> *<f-4> Because helpers we had in great numbers.*
> *<f-3> […] That's because we in Austria, with our column-oriented system, expect a fixed number of required leadership positions. But that this system is suddenly expanded and additional leaders are required for the newly added structures, well …*

A 'column-oriented system' refers to an organisational structure with more depth than width; where a leader is responsible for the 'column' (of persons) behind them. The more volunteers participate, the more columns (and leaders) are needed, which can ultimately lead to a shortage on persons in commanding (leading) positions. *<f-2>* and *<f-3>* argued for greater scalability of existing structures, to better accommodate large numbers of new volunteers. *<f-1>* suggested using the time between incidents to qualify volunteers for leadership positions.

A faster and more flexible registration process for newly arriving volunteers is one possibility to accommodate spontaneous volunteers (*<f-1>*). In contrast to previous volunteer programmes, where *a priori* registration and training was required, spontaneous volunteers have the option to sign up on premise and subsequently contribute immediately. Registration was done with pen and paper to enable *ad hoc* data collection, due to the easy availability and high reliability of the medium (*<f-1, f-4>*). However, the paper-based medium has issues:

> *<f-2>: But the data of these contributors, do you submit them [into the established volunteer programme database]?*
> *<f-1>: No, that is currently not planned. At the moment, it is a mountain of paper that awaits digital inventory.*
> *<f-2>: That is exactly the challenge, yes. Well, such a sheet of paper, that has been signed, with some data on it – that just piles up somewhere.*

This suggests difficulties in information management and later analysis. Low interoperability of registrations forms between organisations aggravates this issue, as volunteers must repeat the registration processes at every organisation or site they wish to become active at. This, in turn, can lower the acceptance towards the process.

As spontaneous volunteers are not familiar with the nomenclature, procedures, and rules in CDM they need a form of leadership that varies compared to that of affiliated or pre-registered volunteers. Formal response organisations can benefit when allowing the creativity of spontaneous volunteers to manifest. As *<f-6>* puts it: 'Very good ideas come from that [inclusion of spontaneous volunteers], ones that we have not thought about before'. However, they must allow for inclusive styles of leadership.

> *And it worked best with [an inclusive] form of leadership. He [spontaneous volunteer] would probably have despaired with any commander that first instructs him on how to park so that the car is pointed toward the direction of escape and that the tank needs to be three quarters full (<f-6>)*

Providing Structure for Opportunistic Affiliation (Figure 1, VI)

The logical continuation of the accommodation of spontaneous volunteering leads towards providing a framework for what we have named *opportunistic affiliation*. Opportunistic affiliation is the act of utilising the participation structures provided by formal organisations on an *ad hoc* basis. The volunteer decides to 'do something' and acts on this decision by registering with a formal organisation on site. Both the decision and execution happen in a short timeframe. Management of opportunistic affiliation requires corresponding organisational structures. Answering *<f-3>*'s question as to the extent of the term *volunteerism*, *<f-6>* puts it thus:

> *I think you have to look at it as something larger. And that is a task for us as commanders. To not think of volunteers only as those who are overly socialised in our field anyway. Those don't need a lot of instructions. They are in the know anyway. It's more difficult with people that joined recently, that come spontaneously or especially the convergent volunteers who are there. For them, I have to provide structures of meaning[3]. (<f-6>)*

The statement implicates that volunteers can exist without formal structures and that structures can exist without a standing corps of volunteers. This represents an empathic view on volunteer management, compared to a traditional command and control approach. It holds formal organisations accountable to provide meaningful structures for spontaneous volunteers.

Participants found it worthwhile to address persons that are not actively looking for participation as part of the formal response system. <*m-2*> points out that many opportunities to participate are simply not noticeable. <*f-1*> mentions that 'a lot is being left out on the street. Potential, you know?' and <*f-4*> adds: 'because nobody asked them.' For this, <*f-3*> proposes a standardised symbol to signal volunteer opportunities *in situ*. The goal, from the authors' perspective, is not so much to attract persons that would otherwise not have become volunteers; rather, it is to make spontaneous volunteers aware that there are opportunities to become active as part of a larger organisation, instead of on their own.

A clearly visible point of contact for arriving volunteers can help formal organisations to both, distribute information and gain overview. <*f-3*> describes the need for a distinct point of reception to lower the entry barrier for spontaneous volunteers:

> *And then I'd go in and there'd be someone who is clearly visible as the person, I don't know, by wearing a hat or something, you know. I'd talk to him, he is my contact person now and knows what is going on. (<f-3>)*

<*f-1*> agrees that this could work well for small operations. However, they add that this concept would need scalability in case of major events. One person would be overwhelmed, with crowds of volunteers arriving. <*f-4*> states, with <*f-3*> affirming, that a single point of contact has been lacking during the recent crisis. Such single point of contact should also relay volunteers to their contact on site (if the contact point is not working as *liaison* outright), inform them about their insurance status, and their tasks while volunteering.

<*m-1*> reports that volunteers expend much effort at the beginning of the crisis; burning off most of their energy and over-exerting themselves. The problem of burn-out is especially prevalent for spontaneous volunteers as emergency organisations have no appropriate tools in place to oversee spontaneous volunteers on site. <*f-1*> speaks of 'helper syndrome':

> *Volunteers are in a grey area; they are allowed [legally] to work as long as they want. We had volunteers who were-- helper syndrome, they were there for 24 hours. Or longer. And they believe they must save the world and they are the only ones that can help. And you have to protect them from themselves. That is our task as organisation. (<f-1>)*

Apart from the aspect of over-extension, representatives of emergency organisations also ask for some procedure to debrief volunteers. A debriefing must include an offer for post-service support, or as <*f-3*> puts it: 'somewhere they can go if they suddenly aren't able to sleep anymore. You know, because 24 hours [working] in an emergency shelter? Hats off to them'. <*f-2*> states that, while they provided support for their equivalent of permanent disaster volunteers, they failed at reaching out to spontaneous volunteers:

> *We did not manage that so well. To reach [spontaneous volunteers] and tell them: 'listen, if you go home now and find that things are affecting you, longer and more frequently – we appreciate that you were here and helped us, but we can help you too!' (<f-2>)*

<*f-1, f-2, f-3, f-4*> agree that support structures must also include ways for volunteers to reflect on their experience and give feedback to the formal organisation.

> *<f-3>: It becomes easier for the people if they have the option to provide feedback.*
> *<f-1>: And the people want to talk about it. They are glad if they can talk about it. […]*
> *<f-2>: One can clearly see that now, when the focus lies on humanitarian help […], that*

[3] This is difficult to translate unambiguously. The original statement was, '*Weil denen muss ich Sinnstrukturen geben*'. The term 'Sinn' in 'Sinnstrukturen' can indicate both 'sense' and 'meaning', to be interpreted as 'sense of belonging' or as 'contribution with meaning'.

> *people are much more affected emotionally and on the whole. […] Now, on this matter, people write to us all the time, ceaselessly, page after page.*

Feedback can also be used by the formal organisation to draw an adequate picture of the situation for themselves and the public (<*f-1, f-3*>).

INTERPRETATION OF RESULTS AND IMPLICATIONS FOR TECHNOLOGICAL SUPPORT

Regarding *RQ1* (the perception of volunteer efforts by formal organisations), we encountered a generally positive stance on the side of formal organisations. Formal organisations tried to receive and integrate individual spontaneous volunteers, rather than attempt to suppress spontaneous contribution. With regards to *RQ2* (measures put in place to integrate spontaneous volunteers), we identified a need for rapid registration processes. The overhead of sign-up procedures and the timeframe between registration and volunteer activity are reduced; by providing reception (sign-up) on site and facilitating quick contribution. Even though measures for pre-registration had been put into place several years prior to the event, impact on preventing spontaneous contribution seems limited. Regarding *RQ3* (the obstacles encountered in the integration of spontaneous volunteers) we see challenges in the unpredictable influx of volunteers. These challenges are in part organisational, and in part technological of nature: in the organisational part, there is a lack of scalability in command structures and a need to adopt appropriate leadership styles. In the technological part, paper-based registration does not scale well over time or with an increasing amount of arriving volunteers. We discuss the implications of *RQ3* in the following section.

Implications for Command and Control Studies

While successful pre-registration programmes for volunteering are in place in Austria, the extent of self-determined contribution during the migration crisis is unprecedented in recent memory. We surmise that pre-registration programmes do not preclude a large amount of spontaneous volunteers. This assumption is based on the formation of large, self-organised volunteer groups, as described in literature (Kornberger et al. 2017; Simsa 2017; Zettl et al. 2017) and documented by high media coverage. Therefore, we propose a complementary *modus operandi*. The chain of dynamics (III) → (V) → (VI) implicates an evolving approach to spontaneous volunteering. The spontaneous nature of contributions and decreased identification of volunteers with formal organisations (III) have necessitated that the formal response system adapt to accommodate it by providing fast registration processes (V). This points towards a more fleeting form of affiliation, eventually leading to what we have named *opportunistic affiliation* (VI). Using opportunistic affiliation, citizens sign up on the spot (*ad hoc*) to conduct spontaneous participation through mature structures provided by formal organisations. Opportunistic volunteers often are (initially) indifferent to an organisation's identity and do not necessarily plan to become socialised within the organisation, or join it formally. Later, they potentially shift their affiliation to another organisation, to contribute towards a different project or perceived need.

Supporting opportunistic affiliation poses an organisational challenge to command and control structures. Two organisational changes appear crucial. First, a change to the prevailing traditional meaning of 'volunteer'; where they are affiliated with, and part of, a formal organisation (Whittaker et al., 2015). In the traditional understanding, a volunteer always exists, epistemologically, as part of *one* organisation; put differently, the system in which the volunteer exists is limited to one formal organisation. If volunteers affiliate with a different organisation, they become a different volunteer – their experience, capacity and skills not proven in the new system, thus facing a 'legitimacy hurdle' (Barsky et al., 2007). To support opportunistic affiliation, it is necessary to understand the volunteer as an entity that exists independent of any formal organisation. Second, command and control structures require surge capacity to manage the unpredictable influx of opportunistic affiliates. We hypothesise that pre-registered, trusted volunteers can be trained *a priori* for leadership positions in expanding command structures, as suggested by <*f-1*>. In this scenario, pre-registered volunteers would be deployed not only to support the relief efforts through direct contribution; but also to cope with the influx of spontaneous volunteers. Further operational requirements to support opportunistic affiliation are: visibly indicating participation options, offering a single, well-marked point of reception on-site, fast registration processes and support structures to prevent overworking.

Based on the organisational implications of opportunistic affiliation and the technological challenges in volunteer reception, we propose two applications for computational support that can help to the integrate spontaneous volunteers: 1) verification and long-term storage of digital volunteer data and 2) selective digitalisation of reception and registration processes to provide scalability.

Digital Verification of Experience (Figure 1, A)

Cone *et al.* (2003) have previously stated that 'without a means of real-time validation, [unknown individuals] are irrelevant to an incident commander' while Barsky *et al.* (2007) described how volunteers can become 'sidelined' because their capacity, background, and knowledge are difficult to verify. Quick and reliable verification of a volunteer's background and previous interactions with the formal response system could help to identify volunteers to fill gaps – or determine who is granted access to the incident area at all.

One technological implementation of this could be achieved through a distributed, permissioned ledger system, consisting of a complete list of a volunteer's previous experiences and activities in CDM. Whenever a volunteer participates in CDM, the formal response organisation adds the participation to the ledger (transaction). The transaction is verified by the organisation that enters it. Metadata can enhance transactions detailing the skills shown or gained of the volunteer. Finally, a body of formal response organisations (forming a trusted consortium) participating in the distributed ledger verifies every transaction. Therefore, any identification that is linked to transactions in the ledger enables a volunteer to immediately present a certified history of prior involvement with the consortium. To ensure privacy, read access needs to be restricted to the consortium and trusted individuals (e.g., the volunteer that is concerned by transactions). The concept of a distributed ledger implicates a persistent digital persona for volunteers, which we will discuss in the next section.

Persistent Digital Persona and Reception (Figure 1, B)

Computer supported registration processes can provide the scaling required when coping with opportunistic affiliation. While dedicated areas for registering, briefing, verifying, and tasking arriving volunteers have been proposed (Sauer et al., 2014), a digital counterpart has not been established (Waldman and Kaminska, 2015). We will discuss computational support by means of a three-stage process:

1) Registration: While digitalising the management of pre-registered volunteers has been addressed by researchers (Auferbauer et al., 2015, 2016), the registration of volunteers is still primarily done by pen and paper.

> *Now, [the registration protocol] is simply a sheet of paper. And the people at the other shelters, they don't know if this sheet has been submitted already or not. This is very important, so that [the volunteer] has insurance. We managed to make people internalise this: if there is uncertainty, fill out the form again. We can always discard it later. (<f-1>)*

Pen and paper are obtainable under most conditions and highly reliable. However, their scalability and sustainability are limited. Participants themselves suggested that this could be solved by *a priori*, digital registration 'as a self-service' (e.g., a smartphone application) while a volunteer is still on their way to the site (<*f-1*>). As part of the self-service registration process, volunteers should be linked to their contact on site (<*f-1, f-3*>). The last step, even in a digitalised registration process, has to be a personal check-in to brief the volunteer and not completely devoid this process of human interaction (<*f-3*>). From a process-oriented, technological perspective, this would be the step where a unique identifier is created and verified for the volunteer, based on the data they have entered digitally. This unique identifier is a prerequisite for the stage 2.

2) Digital Persona: if a digitalised registration process is implemented, a persistent digital persona for volunteers can be generated. There are two options for introducing a digital persona. The first option is to let the entirety of a volunteer's previous participation, as registered in a distributed ledger system, constitute the persona. The second option decouples a volunteer's personal data from their activity and implements a locally stored 'volunteer passport'. This way, each volunteer stores their profile locally on their own smartphone. Such a local volunteer profile is created during registration and is verified and digitally signed by the registering organisation.

3) Check-in / Check-out: Cone *et al.* (2003) pointed out that spontaneous volunteers are not part of any formal accountability system. This makes it difficult for official response organisations to contact them or track their presence. Such accountability would be necessary to prevent overworking (<*f-1, f-3*>), for debriefing (<*f-3, f-4*>) or for support requests (<*f-2, f-3*>).

> *It is not certain that in all cases that [volunteers] will come out of the shelters again [on their own]. Because they could get into a situation where I, representing an organisation, need to know: did they leave at all? (<f-3>)*

A computer supported, digitised check-in and check-out point can be supplied for volunteers that already have a digital persona. To find suitable locations that serve as such checkpoints will require further research. Technologically, there are multiple options for digitalised check-in and check-out points: near field

communication (NFC), radio frequency identification (RFID) or Bluetooth appear viable for fast data transmission between mobile devices and situated checkpoint terminals.

DISCUSSION

This paper presents a systematic description of the mutual effects between spontaneous volunteering and the formal response system's endeavour to accommodate it. Building on top of this description, we identified areas for improvement and gave indication for technical backing and assistance. There are two aspects about (technological) support for opportunistic affiliation that we will discuss in detail.

Privacy and Human Factors in Digitalisation

Throughout our research project, participants – emergency organisations and mediating agencies – emphasised the importance of human interaction. All participants highlighted human beings over web portals or information kiosks or billboards, when referring to contact points or volunteer receptions. Thus, even though we propose technological support, we would stress the importance of face to face interaction.

Creating persistent volunteer personae entails transparency that can both: foster trust and harm personal privacy. Volunteers must, at all times, have sovereignty over their data, the procession thereof must be transparent and data procession must not happen without explicit permission. However, even data that is shared willingly has implications when recording a volunteer's activity. If a volunteer's data becomes public (as the result of a data breach, policy change, etc.), it can have unintended societal effects. Volunteers may experience negative backlash, as during the migration crisis, or receive retro-active benefits for their past volunteer activity. Especially the latter can encourage misuse of the system, e.g., tempering with digital profiles.

Temporal Event Progression and Relation to Emergent Groups

Figure 1 shows a model of the interactions between formal response organisations and spontaneous volunteers during the response phase of an event. However, these interactions are embedded in larger temporal and organisational context. Figure 2 depicts said context. Elements related to opportunistic affiliation are represented by shaded elements.

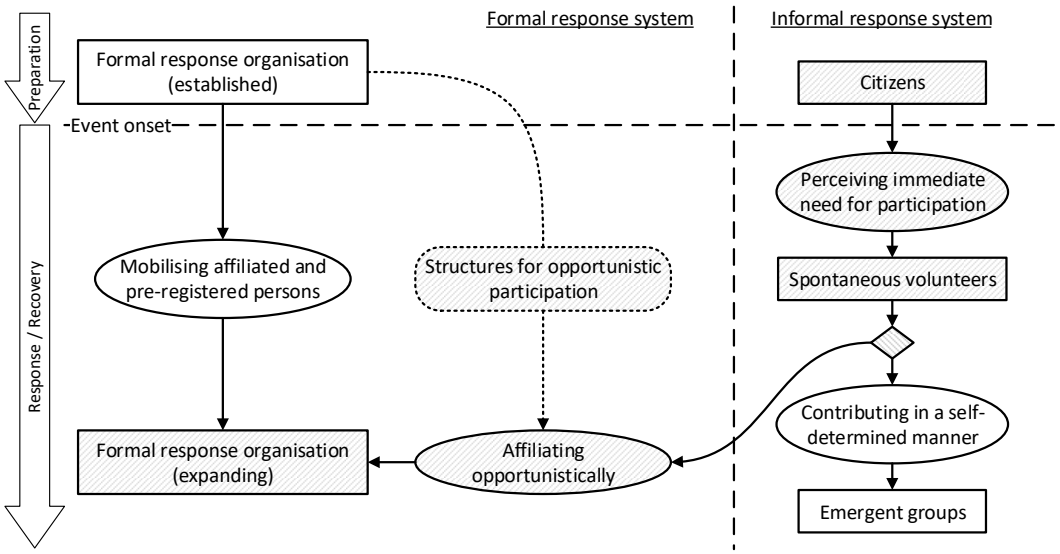


Figure 2. Temporal and organisational context of spontaneous volunteering and opportunistic affiliation

As depicted by the right-hand side path of Figure 2, citizens that do not become affiliated (opportunistically or otherwise) may participate through their own devices in an informal response system. When unaffiliated citizens collectively address perceived shortcomings in response efforts, if demands for relief are not met or existing structures are insufficient, self-organisation will result in *emergent groups* (Drabek and McEntire, 2003; Quarantelli, 1994). Emergent groups do not exist before a disaster and form new structures *ad hoc* in the power vacuum that may occur in the event's immediate aftermath (Lowe and Fothergill, 2003; Simsa et al., 2018). Research on emergent groups in the context of the migration crisis has been carried out by others. Simsa et al. (2018) link the formation of emergent groups to the inability to flexibly incorporate spontaneous participation in formal structures. Kornberger et al. (2017) point to the attractive opportunities for participation that emergent

groups offer spontaneous volunteers. Through their highly flexible structures, emergent groups present a favourable option for spontaneous volunteers, even when formal organisation have established presence. Thus, emergent groups have been proposed as intermediaries (Zettl et al., 2017) or links to spontaneous volunteers (Skar et al., 2016). Our work suggests that emergent groups are bolstered by spontaneous volunteers who have acted neither on offers for pre-registration, nor options of opportunistic affiliation (assuming these exist). Thus, we currently see two potential approaches for command and control to address spontaneous volunteers and emergent groups:

1) Offer forms of participation that are equally attractive as those of emergent groups. In this paper, we discussed opportunistic affiliation for that very purpose.
2) Accept emergence of self-organised groups and utilise their maturing structures as buffer between formal response and convergent, spontaneous volunteers.

CONCLUSION

Volunteers are an important part in crisis and disaster management, as they can provide surge capacity, but also flexibility and creativity. However, volunteers become more self-determined and spontaneous in their decisions to contribute, shifting away from long-term affiliation and detaching from formal response organisations. This autonomous and spontaneous behaviour poses a challenge for command and control structures: to integrate the activity of such spontaneous volunteers into traditional methods and procedures. Doing so is necessary, not only to utilise the capacity of spontaneous volunteers, but also to mitigate disruption of formal response efforts and prevent loss of health.

In this paper, we give a systematic description and analysis of the dynamics that emerged between spontaneous volunteers and formal organisations during the migration crisis affecting Europe in 2015. The increasingly short-term forms of volunteering lead formal organisations to accommodate spontaneous volunteers, especially through the adaption of registration procedures. The extrapolation of this trend leads to opportunistic affiliation, where structures of formal organisation are used for short-term volunteer participation, on the spot. This requires a high degree of flexibility that information technology can help to provide. We show how digitalisation of volunteer reception and a digital, secure, distributed information storage can be used to achieve both: better scaling of spontaneous volunteer management, and building trust. Implementing such a system facilitates opportunistic affiliation, one possible approach to spontaneous volunteer management.

ACKNOWLEDGMENTS

We would like to thank the participants of our group discussions and interviews for their time and contribution.

This work was funded by the Österreichische Forschungsförderungsgesellschaft mbH under the Research Partnership Programme: 'The Industrial PhD Programme 2015' - Grant No. 851629

REFERENCES

auf der Heide, E. (2003) Convergence behavior in disasters, *Annals of Emergency Medicine*, 41, 4, 463–466.

Auferbauer, D., Ganhör, R., and Tellioğlu, H. (2015) Moving Towards Crowd Tasking for Disaster Mitigation, *Proceedings of the ISCRAM 2015 Conference*, L. Palen, M. Büscher, T. Comes, and A. L. Hughes, eds., Kristiansand, Norway.

Auferbauer, D., Ganhör, R., Tellioğlu, H., and Pielorz, J. (2016) Crowdtasking: Field Study on a Crowdsourcing Solution for Practitioners in Crisis Management, *Proceedings of the ISCRAM 2016 Conference*, A. H. Tapia, P. Antunes, V. A. Bañuls, K. Moore, and P. de J. Albuquerque, eds., Rio de Janeiro.

Barsky, L. E., Trainor, J. E., Torres, M. R., and Aguirre, B. E. (2007) Managing volunteers: FEMA's Urban Search and Rescue programme and interactions with unaffiliated responders in disaster response, *Disasters*, 31, 4, 495–507.

Braun, V., and Clarke, V. (2006) Using thematic analysis in psychology, *Qualitative Research in Psychology*, 3, 2, 77–101.

Britton, N. R. (1991) Permanent Disaster Volunteers: Where Do They Fit?, *Nonprofit and Voluntary Sector Quarterly*, 20, 4, 395–414.

Cone, D. C., Weir, S. D., and Bogucki, S. (2003) Convergent volunteerism, *Annals of Emergency Medicine*, 41, 4, 457–462.

Drabek, T. E., and McEntire, D. A. (2003) Emergent phenomena and the sociology of disaster: lessons, trends and opportunities from the research literature, *Disaster Prevention and Management: An International Journal*, 12, 2, 97–112.

Dynes, R. R. (1994a) Situational Altruism: Toward an Explanation of Pathologies in Disaster Assistance, *XIII World Congress of Sociology*, Bielefeld, Germany.

Dynes, R. R. (1994b) Community Emergency Planning: False Assumption and Inappropriate Analogies, *International Journal of Mass Emergencies and Disasters*, 12, 2, 141–158.

Fritz, C. E., and Mathewson, J. H. (1957) Convergence Behavior in Disasters: A Problem in Social Control, *American Sociological Review*, 23, 9, 102.

Harris, M., Shaw, D., Scully, J., Smith, C. M., and Hieke, G. (2017) The Involvement/Exclusion Paradox of Spontaneous Volunteering, *Nonprofit and Voluntary Sector Quarterly*, 46, 2, 352–371.

Helsloot, I., and Ruitenberg, A. (2004) Citizen response to disasters: A survey of literature and some practical implications, *Journal of Contingencies and Crisis Management*, 12, 3, 98–111.

Hustinx, L., and Lammertyn, F. (2003) Collective and Reflexive Styles of Volunteering: A Sociological Modernization Perspective, *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations*, 14, 2, 167–187.

Hyde, M. K., Dunn, J., Scuffham, P. A., and Chambers, S. K. (2014) A systematic review of episodic volunteering in public health and other contexts, *BMC Public Health*, 14, 1, 992.

Kallius, A., Monterescu, D., and Rajaram, P. K. (2016) Immobilizing mobility: Border ethnography, illiberal democracy, and the politics of the 'refugee crisis' in Hungary, *American Ethnologist*, 43, 1, 25–37.

Kornberger, M., Leixnering, S., Meyer, R. E., and Höllerer, M. A. (2018) Rethinking the Sharing Economy: The Nature and Organization of Sharing in the 2015 Refugee Crisis, *Academy of Management Discoveries*, 4, 3, 314–335.

Lowe, S., and Fothergill, A. (2003) A need to help: Emergent volunteer behaviour after September 11th, *Beyond September 11th: An Account of Post-Disaster Research*, 293–314.

Plagnol, A. C., and Huppert, F. A. (2010) Happy to Help? Exploring the Factors Associated with Variations in Rates of Volunteering Across Europe, *Social Indicators Research*, 97, 2, 157–176.

Prince, S. H. (1920) Catastrophe and social change - based upon a sociological study of the Halifax disaster, Columbia University, New York, NY, USA.

Quarantelli, E. L. (1994) Emergent Behaviors and Groups in Crisis Time of Disasters, University of Delaware Disaster Research Center, Preliminary Paper #206.

Sauer, L. M., Catlett, C., Tosatto, R., and Kirsch, T. D. (2014) The Utility of and Risks Associated With the Use of Spontaneous Volunteers in Disaster Response: A Survey, *Disaster Medicine and Public Health Preparedness*, 8, 1, 65–69.

Scanlon, J., Helsloot, I., and Groenendaal, J. (2014) Putting It All Together: Integrating Ordinary People Into Emergency Response, *International Journal of Mass Emergencies and Disasters*, 32, 1, 43–63.

Simsa, R. (2017) Leaving Emergency Management in the Refugee Crisis to Civil Society? The Case of Austria, *Journal of Applied Security Research*, 12, 1, 78–95.

Simsa, R., Rameder, P., Aghamanoukjan, A., and Totter, M. (2018) Spontaneous Volunteering in Social Crises: Self-Organization and Coordination, *Nonprofit and Voluntary Sector Quarterly*, 48, 103-122.

Skar, M., Sydnes, M., and Sydnes, A. K. (2016) Integrating unorganized volunteers in emergency response management, *International Journal of Emergency Services*, 5, 1, 52–65.

Starbird, K., and Palen, L. (2013) Working and sustaining the virtual 'Disaster Desk', *Proceedings of the 2013 Conference on Computer Supported Cooperative Work*, ACM Press, New York, USA, 491–502.

Twigg, J., and Mosel, I. (2017) Emergent groups and spontaneous volunteers in urban disaster response, *Environment and Urbanization*, 29, 2, 443–458.

Waldman, S., and Kaminska, K. (2015). Connecting emergency management organizations with digitally enabled emergent volunteering Literature review and best practices, *Report 2015-R271*, Defence Research and Development Canada – Centre for Security Science.

Whittaker, J., McLennan, B., and Handmer, J. (2015) A review of informal volunteerism in emergencies and disasters: Definition, opportunities and challenges, *International Journal of Disaster Risk Reduction*, 13, 358–368.

Zettl, V., Ludwig, T., Kotthaus, C., and Skudelny, S. (2017) Embedding unaffiliated volunteers in crisis management systems: Deploying and supporting the concept of intermediary organizations, *Proceedings of the 14th ISCRAM Conference*, T. Comes, F. Bénaben, C. Hanachi, M. Lauras, and A. Montarnal, eds., Albi, France, 421–31.

Analysis of Common Operational Picture and Situational Awareness during Multiple Emergency Response Scenarios

Kristine Steen-Tveit
Centre for Integrated Emergency Management, University of Agder, Norway
kristine.steen-tveit@uia.no

Jaziar Radianti
Centre for Integrated Emergency Management, University of Agder, Norway
jaziar.radianti@uia.no

ABSTRACT

Disaster response operations require communication and coordination between agencies that seldom occurs in everyday workday situations. Furthermore, in such hybrid environments it is necessary to establish a common operational picture for the responders involved to support collaborative decision-making. The emergency responders must gain situational awareness, and this can further affect the quality of how they deal with the situation. Training in emergency situations is shown to be efficient for learning. In order to understand the complexity of working in unpredictable environments, an analysis of an audio-log from a large-scale drill was carried out. Moreover, this paper provides a definition of several categories for identifying the processes to establish situational awareness and a common operational picture among emergency responders. The analysis process revealed how the actors communicate and revealed an overall communication pattern.

Keywords

Full-scale drill, elicitation methods, situational awareness, common operational picture, information needs.

INTRODUCTION

In many complex emergency settings, both those that are man-made and natural disasters, the emergency response organizations must collaborate and understand different situations before appropriate life-saving decisions and preventions of major damages can be made. This requires planning, exercises, robust radio networks, professional actors and custom technical solutions. Developments in society indicate that the emergency organizations will face more complex operations in the future and meet new types of situations. The incorporation of the new technologies and improved collaboration and information sharing modes have added to these complexities. Taking Norway as an example, a new emergency platform (nødnett) has been operational in all districts of Norway since 2015 (nødnett.no). The system was intended to enhance interdisciplinary communication between emergency services and other organizations participating in rescue and emergency work.

Literature has revealed that the quality of the response and recovery efforts is directly linked to the knowledge and skills possessed by the staff working at disaster sites and their ability to put them into practice in a range of hazard events (Schaafstal, Johnston, & Oser, 2001; Sinclair, Doyle, Johnston, & Paton, 2012). Training in emergency situations provides valuable experience for those involved in emergency management organizations. Studies in this area show that a common factor in failures is human errors, and poor communication between the different actors involved is, in many cases, identified as a contributing factor (Lelardeux et al., 2017). Likewise, in our example of practices in Norway, there are numerous drills that have been conducted to allow responder organizations to collaborate and become acquainted with the new technologies.

Situational Awareness (SA) and Common Operational Picture (COP) are two important properties required when various emergency response stakeholders must cooperate to handle a large crisis with multiple events that might cause major critical infrastructure hazards or life-threatening consequences. The COP is created by those involved after considering the information that is available in a situation and consists of a description of what is

going on, predictions for the future, and factors such as resources and actions (Borglund, 2017). The creation of a COP is important for the success of the emergency management and it is crucial that those involved create and maintain a common situational picture of the situation (Borglund, 2017). Borglund (2017) also emphasises that the COP is important for the decision-makers to make better decisions in the coordination of the operative units through the different stages of the event. The literature describes COP as a checklist of the characteristics in a certain situation within a geographical area, and is also characterized as a display of relevant operational information, such as positions, infrastructure and different resources (Karagiannis & Synolakis, 2016). If the collaborating organizations are focusing only on their own tasks, this is a factor that limits the COP and generates information-gaps (Norri-Sederholm, Joensuu, & Huhtinen, 2017). In addition to SA, the organizations involved need to know each other's key elements, such as needs, goals, expectations, culture, capabilities and procedures in order to achieve effective cooperation (ibid).

While the idea of advancing the crisis communication infrastructure in Norway is to improve the communication between organizations, and enhance the SA and COP, there is a limitation in studies on how to analyze the development of SA and COP. This paper analyzes the SA and COP based on a full-scale drill conducted in a Norwegian city. It was a complex scenario in which multiple emergency events in three different places occurred almost simultaneously. The drill was designed in such a way that none of the involved emergency management stakeholders knew the details and had to react in "real-time" based on the information flow being exchanged. This drill focused on the collaboration in the field as well as with the command and control centers (Fire Service 110, Police 112 and Ambulance 113). The content of this article is derived from this drill.

The overall goal of this paper is to contribute to a better understanding of the complex and unpredictable working environment when the various emergency organizations need to collaborate and communicate in order to gain COP. The establishment of COP is one important aim during large police operations. Hence, the aims of this paper are threefold: First, this paper defines a method and concept categorizations that enable us to analyze the audio-log, and identify the process of establishing the SA and the COP. Second, we analyze and visualize the communication and interaction patterns between the emergency response organizations. Third, we conduct a reflection exercise to assess if our audio-log analysis method is a promising way to observe the SA and COP.

This paper is divided into five sections. The related work section reveals important related studies and the state of-the-art nature of SA and COP, while the methodology part explains the research process, data collection and data analysis. The results part presents the findings of this study and the discussion. The paper ends with conclusions and future work.

RELATED WORK

The previous studies have examined two main themes with respect to emergency operations: the bottleneck that prevents the effectiveness of the cooperation between the different agencies (Seppänen, Mäkelä, Luokkala, & Virrantaus, 2013) and collaboration both in practice and research. The challenges related to coordination in multi-agency emergency management are well documented by several studies and retrospective analyses (Comfort & Kapucu, 2006; McEntire, 2002; Perry, 2003). It is important to learn from previous events and conduct new research as new features in emergency management emerge, such as how to coordinate multi-organizational crisis communication in common call groups over radio networks. Such new and custom tools might be a solution to the fact that collaboration between emergency response organizations has been abandoned on emergency sites (Berlin & Carlström, 2011).

Several studies have been conducted focusing on team performance, and communication is an important feature for coordinating teamwork and gain situational awareness through transactions of different information (Sorensen & Stanton, 2016). Prior research on large-scale coordination in emergency response exposes several specific issues related to communication. One of the main problems seems to be that the emergency responders are unable to obtain needed information (Militello, Patterson, Wears, & Ritter, 2005). Sharing information is important, but the extent of which information that is being shared is also a factor to consider (Bharosa, Lee, Janssen, & Rao, 2009). Everyone involved has his/her own experience and professional background which is important for what information they prioritize and build situational awareness upon. This information is the basis for the action of the operative units, and for building a COP with the other organizations involved. This underlines the importance that the actors develop an understanding of the extent of the situation quickly, also relative to the use of plans, stress management and the use of technical tools (Steigenberger, 2016).

There are some factors that are significant in COP: Structure, representation, processes and management (McNeese et al., 2006). COP is a structure for available information to be collectively transformed by the actors into knowledge. COP is a representation of the knowledge, and an object that provides a process, decision and actions based on the structure and representation. Finally, it is the knowledge management that utilizes the aforementioned factors of COP that facilitate the actors` possibilities to solve the tasks in hand.

The development of COP starts from the bottom-up perspective where the actors or witnesses provide the command and control centers with basic information needs, and then the knowledge must be processed and distributed back to all relevant actors.

SA plays an important role in safety and performance. It has expanded from being used for pilots to many other domains - the difference lies in the elements you are looking for. Especially in situations where the environment is complex, the actors need to ascertain critical cues to determine which decisions to make (Endsley, 1995). In emergency management, the agencies experience chaos and need accurate information to carry out a good response. But without effective coordination and communication, which are crucial aspects of achieving COP, situational awareness is impossible to achieve (Karagiannis & Synolakis, 2016).

Another aspect of major emergencies is the information overload that is created by many inquiries which provide redundant and irrelevant information (Laakso, Palomäki, & Change, 2013). For instance, when the Command and Control Centers (CCCs) are collecting data from inquiries, they need to perceive what the basic information is, and in this case, it is the critical cues that matter. If the dispatcher does not know what critical cues to provide for SA in that situation, the potential for error will increase. There could be more than one reason as to why the dispatcher does not receive the available information; for instance, in a major event accuracy in the data collection is required because of the data overload. It is important to embrace the fact that not all information is relevant to all actors involved in the operation. Therefore, the organization`s situational understanding should involve both specific information needs for themselves, and what information they hold and need to share with other actors (Luokkala & Virrantaus, 2014). In this way those involved can both achieve SA for themselves and contribute to collaborating with regard to the actor's SA. There are three levels of SA. Endsley (1995) describes them as following:

At level 1 SA, the perception of the elements in the environment is crucial. At this level, the actors must use their senses, and in a CCC this means audio and the information they can get from the applicable technological tools (Geographical Information Systems (GIS) and other Information Systems such as health or alarm systems). An example would be a car accident where the eye-witness would report the information and some understanding of the surroundings. The GIS would relate, approximately, the location of the accident, and information about the topography. At level 2 SA, the emergency management actors would need to put together the information from level 1 and make sense of it. They would need to understand the "so what" of the information. For instance, the degree of damage to the car would indicate the energy involved and, further to this, the trauma inflicted upon the passenger. At level 3 SA, the experienced dispatchers would be able to project what might happen in the near future, such as a car in the middle of the road providing a risk of a new accident with other cars driving into it.

Several studies show that one of the key factors in human errors involves challenges related to SA (M. R. Endsley, 2018). For instance, at level 1 SA, the dispatcher may fail to perceive the critical cues that are important. There are several reasons for this, for instance a failure in the system or lack of reliable information (Endsley, 1995). In many cases, the lack of an adequate or internal model for streamlining data collection (ibid) can be the cause of errors. Furthermore, at level 2 SA, the dispatcher can misread cues and not consider them to be important for reaching the goal/s in question (ibid). If the actors fail to predict and prevent situations that can result in more damage or new dangerous situations, the reason might be missing level 3 SA.

SA depends on information that can be uncertain and highly volatile (Nunavath & Prinz, 2016) and the organizations often have challenges in finding data that fill their own information needs, and data heterogeneity between the actors is a common problem (van den Homberg, Monné, & Spruit, 2018). If the actors involved focus only on their own tasks, this is a factor that limits the COP and generates information-gaps (Norri-Sederholm et al., 2017). In addition to SA, the organizations involved need to know each other's key elements, such as needs, goals, expectations, culture, capabilities and procedures to achieve effective cooperation (ibid). SA will provide the involved actors with the opportunity to establish COP on the basis of the knowledge on common needs and the possibility to share critical information. In this sense, if not all agencies have SA, they will not achieve COP and, moreover, if they do not achieve COP, the SA will not be sufficient to take action in a multi-agency operation. Therefore, the SA and COP are closely connected and complementary to one other.

A technical solution and reliable environment for collaborating communication are important for the effectiveness of the multi-agencies' (Steigenberger, 2016) possibilities to create COP. There are different call groups in such radio network solutions, and one of the reasons for this is to avoid overcrowded information in one call group, but this is also a reason why information gets lost and fails to reach all relevant actors who would benefit of the information (ibid). In many cases, there are instructions on how the call groups should be used, and how they are required to enhance collaborating and building COP. This communication should ensure that the shared information is passed to the right receiver at the right time, and the information must be important for the SA.

To sum up, previous studies have highlighted the importance of COP, SA, crisis communication, supporting technologies and team collaboration. However, there are limited references on the methodology of how we understand what actually happens with regard to the COP, SA and crisis communication from time to time during the response. This paper attempts to offer a methodology to evaluate SA and COP *during* the response, particularly from the outset of the events until point at which the crisis stakeholders gain control of the situation.

METHODOLOGY

The overall approach of this work was a qualitative method. We combined observation, audio log analysis and interviews with the crisis management stakeholders. However, the main analysis of the situational awareness and crisis communication was based on the audio logs. The observation was carried out during the course of a drill in the field and in the relevant command and control centers (CCC). Both observations and the interviews served as confirmation if there were uncertainties in the audio logs. The methodology is based on an open coding approach which is frequently used in qualitative studies of the characteristics of communication (e.g., Panagiotopoulos, Barnett, Bigdeli, Sams, & Change, 2016).

Crisis response practice in Norway is based on an emergency radio network solution (Norwegian Public Safety Network – Nødnett). This technology is built on TETRA, which is a secured, encrypted communication infrastructure. During an emergency, the CCC will establish several custom call groups, for example a BAPS call group (fire services, ambulance and police services), a SAMVIRKE call group (used in operations which are not defined as rescue operations and where the CCC with their operative units needs to collaborate with actors who do not have access to BAPS). These call groups facilitate expedient and effective cross-sectional communication, and simultaneously ensure confidentiality and security. Additionally, there are other local call groups that are used internally in the agencies. In total, there are 13 call groups that can be established, depending on the type and severity of the crisis. BAPS is controlled and administered by the police. When talking through the radio network, there is a log system that records the conversations.

We made use of the audio logs from BAPS in order to analyze COP, SA and communication patterns in the multiple crisis scenarios of the drill (see Section Scenarios). We analyzed three audio logs consisting of 4.25 hours of recording time in each log to ensure the completeness of the information being exchanged by all actors from the involved agencies. There were mainly six actors communicating in BAPS; the operator from each CCC and the operative leaders (referring to Table 1: ILKO, ILH, ILB). Note that there were several logs of different call groups, but we only used BAPS as permitted by the emergency stakeholders. We reconstructed all the sequences of events and communications in order to make a better dataset with complete communication. The transcription of the audio logs was then coded into the following information: 1) The origin of the information; 2) The destination of the information; 3) The information content, which was furthermore grouped into a main important information exchange as listed in Table 3. This audio log was also triangulated with the real-time logs documented by the police during this multiple-crisis scenario drill.

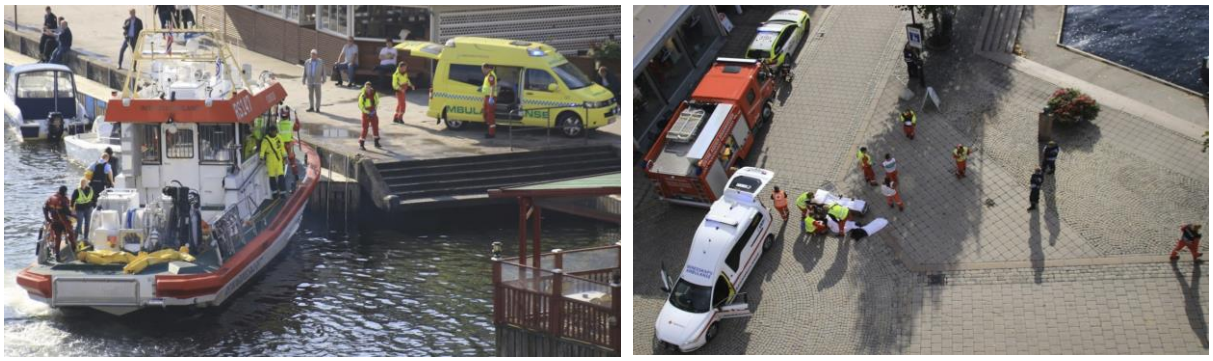


Figure 1 The drill setting in the harbor.

SCENARIOS

The scenarios were built around three different incidents that happend almost simultaneously in a city in Norway. An attack on a bus consisted of 20 student passengers (School Scenario), a traffic accident with injured people (Accident Scenario) and a large crowd attack during a music festival (Harbor Scenario). The largest and most resource-intensive effort was the one that occurred in the harbor. The drill was organized in a quite complex fashion, as it had a common goal, i.e. cooperation among stakeholders in the field and sub-goals of each organization involved. Table 1 describes some common abbreviations used by emergency organizations in Norway. The overall scenario is described in Table 2.

Table 1 Descriptions of Abbreviations used in the Exercise

Abbreviation	Description
PLIVO:	Ongoing life-threatening violence
TG:	Call group
BAPS:	Fire and Rescue services, Emergency Health services and police services – Cooperation Call group. Involved actors must listen to this call group.
FORF:	Volunteer organizations
RS:	Norwegian Society for Sea Rescue
ILKO:	Incident Commander Coordination Point, police
ILB	Incident Commander, fire and rescue
ILH:	Incident Commander Health, ambulance personnel
LA1-4	Ambulance helicopter

Table 2 describes the simplified sequences of events in the drill, summarizing the most important messages being exchanged indicating the milestones of the critical events to respond to.

Table 2 Simplified Scenario Description

Time	**Scenario events**
10:00	Emergency call: *Emergency event. Something unusual is happening on a bus at (anonymized) XX school. Uncertain about what is going on*". New emergency call: "*The bus driver has been thrown out of the bus. He is injured. The bus is driving from the scene with several passengers on board. Information about the direction the bus is going has been provided.* *Police and ambulance are moving toward the site. Opening the BAPS call group.*
10:05	Emergency call: *More specific information is received, the exact number of passengers, some description of the offender, and confirmation of the direction.*
10:10	Emergency call: *New emergency event. A traffic accident in XX intersection. Possible human injuries, unknown extent.* Police performed a triple alert (alerting all emergency CCCs in a conference phone call) and provided a common update on the new emergency event. Custom TGs and BAPS were used. Building a common operational picture.
10:15	Emergency call: *New emergency event. The bus drove into a crowd during a concert at the harbor. Several people injured. Chaos on the site*. New emergency call: *Situation update, caller has perceived the situation as a wanted event (act of terror).* Police defined the situation as PLIVO. Police need to build a common operational picture.
10:15-10:25	Emergency call: *Police CCC receives situation updates:* • *many people hit by the bus and are injured* • *some victims are under the bus, others are inside* • *people observed in the water* • *chaotic emergency site*
10:25	Alerted RS, FORF, the Norwegian Civil Defense and the municipality. Police must build a common operational picture for all agencies involved (using different TG and phone calls)
10:30	Police services had to organize assembly place for the injured/deceased The announcement of ILKO, ILB and ILH
10:30	The municipality had to establish a next of kin center
10:35	Police talked to the media
10:40	Police had to evacuate downtown (the area around the harbor)
10:40-15:00	All emergency responders focused on collaboration on assembly place for injured/deceased

RESULTS AND DISCUSSIONS

One might recall that we used BAPS audio logs as the sources for this analysis. The audio logs were divided into several parts, where the different conversations of the same timelines were split from each other. When going through the conversations the actors were identifiable (both for delivering messages and receiving messages) and the messages were systematized into broader categories, as depicted in Table 3. The categorization process involved structuring the different types of messages into categories based on the similarity of the contents and purposes of the conversations. We only present here the exchanged messages on a macro level without revealing actual conversations with regard to privacy. However, all transcribed messages are well documented and allow us to trace back all the results we achieved. This provides a picture of the SA and COP for the involved agencies.

Table 3 Communication Exchange Categories in the drill

Categories	Coverages
Situation Report	All information flows between the actors contain updated situations in the field
Confirmation	All statements showing the EM organizations have heard, known, understood, and received the information, and acknowledged that certain actions have been taken.
Action Plan	Statements which imply that the actors planned to take action in order to respond to the current state of the situation
Request	An actor requested updated information, resources or support from other stakeholders
Action	All actions taken by the responders and reported to all the participants in the call group
Common Understanding	When each agency involved in the call group confirmed that they had received and understood newly incoming situation reports.
Location	All information related to a location such as providing or confirming a current location or being in a wrong location
Contacting	An actor tries to contact one or several actors in the call group
No Answer	When the addressed actor (s) did not reply to the contact requests
Offer Resources	When one agency offers resources relative to the situation
New Emergency Event	Notifications on the new emergency events
Report Barriers	If the agencies found barriers when performed their tasks
Error	When an actor caused noise or other disruptions in the call group, for instance pressing speak-button by a mistake. An error can be either harmful or unintended for the BAPS
Information Mismatch	When actors have different situational awareness in a specific situation, for instance, if one agency is using resources on a situation that has already been solved by another agency.

As mentioned earlier, BAPS is a call group for the purpose of collaboration and information sharing. It is also used for action planning and for clarifying uncertain information for the involved actors. We need to consider that the agencies use additional other channels beside BAPS for communicating. For example, the observation revealed that the coordinators from one of the CCCs often used the telephone area of the integrated command and control system. This means that this information did not flow in BAPS. This communication was typically a one-to-one conversation. In practice, if this information turns out to be crucial for others, they must inform relevant agencies in a timely manner.

There are several possible explanations as to why the one-to-one conversation occurred: if the information is not considered to be important for all actors, it shall not be passed to BAPS. Deciding exactly what information to share or not is challenging, as is emphasized in the literature. Another explanation might be that BAPS guidelines are designed to prevent data overload.

Figure 2 shows the results of the information categorization from the drill. A large proportion of the exchanged messages are in the situation-report category - 21 percent of the messages. This is a safe way of using BAPS, simply because situation reports may be one of the most effective ways of creating a COP. But BAPS information sharing would require acknowledgement from all emergency responders. In Figure 2, the results show that only 16 percent of the messages fall into the confirmation category, which is a little counterintuitive. There are several more situation reports given than confirmations. In addition, there are several actors involved; there should ideally be a higher frequency of confirmations than situation reports as well. This is reflected in figure 1 that shows 7 % common understanding, i.e. actors from all three agencies confirming that they understand the situation report.

However, this may not portray a correct picture of the situation. The CCC observation of the drill showed that the dispatchers were simultaneously operating different tasks relative to the drill which could be the possible explanation as to why there were a lack of confirmations registered in BAPS.

The different categories can also provide an overview of the different levels of SA. For instance, situation reports can represent level 1, since they involve describing information from the situation. The actors know their own information needs and will share them with other emergency responders. The literature also mentions that it is a challenging task to capture all critical cues, and simultaneously to know the other agencies' needs.

Figure 2 shows that 10 percent of the messages involve some sort of request (request confirmation, repeating and information). These requests might represent the fact that information shared in BAPS is important for all actors, for instance for requesting confirmation ("did you hear that – this is important for you"), requesting repetition ("this is important for my operation, please repeat") and requesting information ("I need more information than I already have"). The situation reports also involve level 2 SA, where those involved update one other as to how they understand the situation. An example is when the police defines the situation as PLIVO (See Table 1 for the definition). The information they have perceived, combined with professional knowledge creates a comprehension of the situation based on disjointed elements from level 1. In this scenario, putting together the critical cues means that the actors need to consider that the situation is threatening and may result in violence, and hence take necessary measures related to that understanding. Moreover, the action category can also represent a level 2 SA, by showing that the actors need to act *in* the situation. Information from level 1 involving, for example, a bus driving into a crowd, provides an understanding of the need for health resources. Further, using this example, the categories *action planning* and *offer resources* are a sign of level 3 SA by the projection of future status. The actors project that the situation might develop into more injured people and dangerous situations.

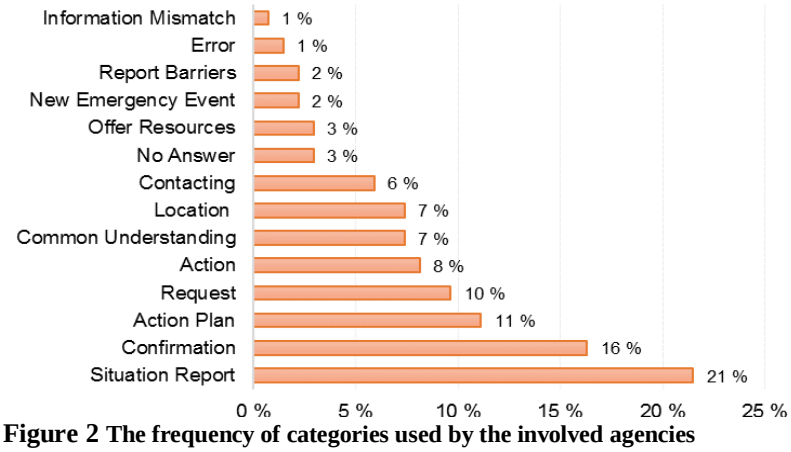


Figure 2 The frequency of categories used by the involved agencies

All involved agencies have in some degree achieved COP and the three different levels of SA. Figure 3 shows which categories the agencies` messages are divided into. We need to consider the internal communication within the agencies, and as an example, ILKO, the police operative unit and CCC112 follow each other closely in every operation and therefore we can assume that the messages are connected to all actors within the organization. The same goes for ILB, the fire operative unit and CCC110, and ILH, the ambulance team and CCC113. Figure 3 illustrates the categories that seem to be important to share amongst the actors. Considering that BAPS is a call group where common information needs are to be communicated, ILKO and ILB share information within more categories than the other actors. Figure 3 also shows that there are no obvious classifications of the categories/messages between the CCCs and the operative leaders (ILKO, ILB, ILH). The assumption as to what information that needs to be shared seems to be directly about the emergency events and does not involve coordination strategies (besides having a COP on location), nor organizational specific information (such as information about patients etc.).

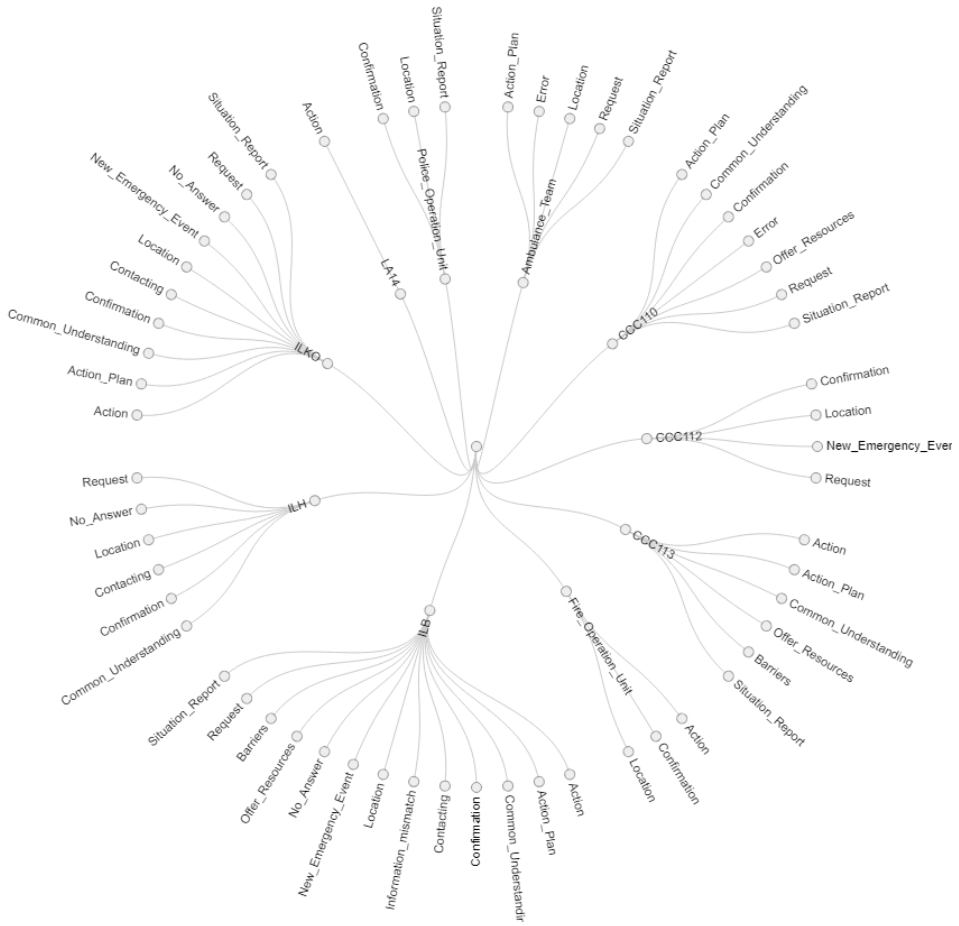


Figure 4 The categories of messages linked to involved agencies

ILKO and ILB share information between more categories and have a higher frequency of messages (see Figure 3) than do the other actors. Figure 4 shows that a large proportion of the messages in BAPS are communication between ILB and ILKO, i.e. they are either receiving a message or addressing a message directly to each other. In this case, it seems that these two actors are providing all the involved agencies with common information needs, which is natural in complex scenarios involving mass injured victims. They are on the site, and ILH carries out administration for the patients (for instance triage and transportation) and the information they hold is not typically information that needs to be shared.

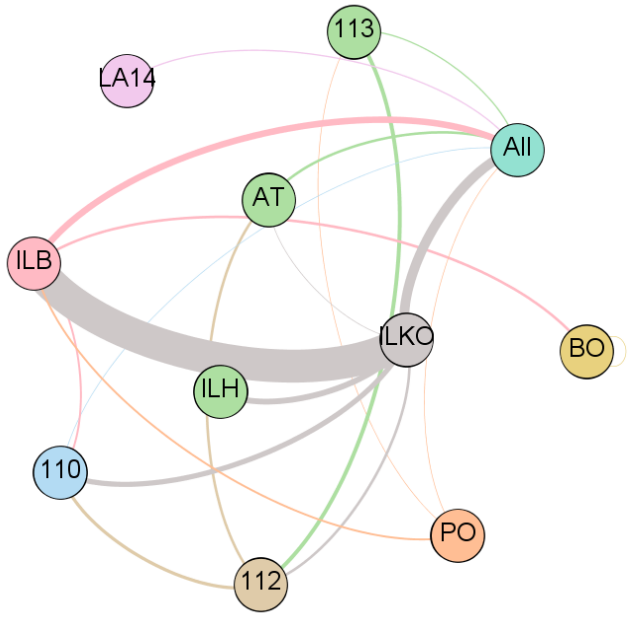


Figure 3 Information flow among involved agencies.

The information flow between the actors might illustrate the need for level 1 SA information to be reported (situational report) from the actors on the site and then be processed by the other actors involved. The information flow also can demonstrate the *structure factor* of COP, referring to the four factors of COP. Some of this information is logged by the CCCs and then the knowledge is representable for the actors with access to the log (for instance the emergency rooms that constantly view the log from CCC 113). The agencies involved have no other tools for visualization of the COP, except for a geographical information system (GIS) that shows the area and the specific resources for each agency. Communication flow is the main factor for COP in these scenarios. A common

GIS for teamwork that provides the same display for all the involved agencies (for instance placed in the CCCs) can provide a tool for explicating the four factors of COP (McNeese, et al, 2006).

The information flow in BAPS can also provide the process factor of a COP, because of the categories *action* and *action plan*. Based on situation reports and requests, the agencies hold information to build decisions and then act on them. The dispatchers in the CCCs and operative leaders on the site manage the information and, together with the collaborative actors, solve the tasks in the emergency scenario.

Using audio logs for analysis provides both great opportunities and some challenges. In this paper, we analyzed the call group for instant information sharing. This gives us the opportunity to carry out a retrospective analysis of the actual conversation during the emergency operation. The audio log systems provide the time aspect and the actual words used, which are in many cases impossible to access. By categorizing the messages between the actors and identifying the features connected to COP, it is possible to gain an overview of the involved actors' COP.

The fact that the agencies have other communication possibilities, such as calling each other in one-to-one communication, provides challenges for capturing the actors' SA in the analysis. For instance, the health services are more likely to use one-to-one communication because of the sensitive information they hold. This could also be an explanation for the much lower frequency of messages from the health services (ILH, CCC113, ambulance team) in Figure 4. Moreover, SA is a process that requires subjective data.

The COP is a factor that can be measured using the audio log such as BAPS call group because the communication provides the insiders' overview during the response stage. Other communications occurring outside of BAPS would provide very little insight, and often be unsystematic in order to be able to derive understanding of the COP establishment process. Concerning the SA, the communication outside of BAPS provides the analysis process with a much more complex component. The SA embraces all the actors' understandings of the situation, hence the internal, agency specific communication will provide SA for actors within their own professional tasks. As far as the COP is concerned, not all of the information is important for achieving this. On contrary, the analysis provided an opportunity to systematize the categories of the messages into different levels of SA. The analysis of the audio log showed that the messages between the actors involved all three levels of SA, but not the involved actors` SA of the entire operation.

CONCLUSION

We have proposed a method to analyze and visualize SA and COP from the audio log of the call group involving the fire, health- and police services. The messages could be systematized into suitable categories. This provided the opportunity to identify COP and SA features and the communication patterns during the operation. The three levels of SA were identifiable among the messages in the call group, but it did not provide a measurement for the involved agencies' SA of the situation due to the presence of internal process and communications outside formal channels that contribute to shaping the SA. Our approach contributes to improving evaluation of SA and COP during the incident response. Traditionally, retrospective evaluation of drills is often challenging because the involved actors are likely to transfer their own vision to the situation based on their own professional standpoint. (Imoussaten, Montmain, & Mauris, 2014). Our approach offers the opportunity to evaluate SA and COP in a more objective way.

The audio log provides a unique opportunity to conduct an analysis of multi-agency operations based on actual communication and the timeline during emergency operations. For future work, we plan to validate our method for real crises, or combine the methods with other qualitative methods to improve our understanding of SA and COP. We also try to relate the proposed categories in this paper to more established theories.

ACKNOWLEDGMENTS

We thank all the emergency management stakeholders in Aust and Vest Agder Counties, Norway, who have provided access to data and resources to conduct this research.

REFERENCES

Berlin, J. M., & Carlström, E. D. (2011). Why is collaboration minimised at the accident scene? A critical study of a hidden phenomenon. *Disaster Prevention and Management: An International Journal, 20*(2), 159-171.

Bharosa, N., Lee, J., Janssen, M., & Rao, H. R. (2009). *A case study of information flows in multi-agency emergency response exercises.* Paper presented at the Proceedings of the 10th annual international conference on digital government research: Social networks: Making connections between citizens, data and government.

Borglund, E. A. (2017). *The role of artefacts in creating a common operational picture during large crises.* Paper presented at the 14th International Conference on Information Systems for Crisis Response and Management, ISCRAM, .

Comfort, L. K., & Kapucu, N. (2006). Inter-organizational coordination in extreme events: The World Trade Center attacks, September 11, 2001. *Natural hazards, 39*(2), 309-327.

Endsley. (1995). Toward a theory of situation awareness in dynamic systems. *Human factors, 37*(1), 32-64.

Endsley, M. R. (2018). Automation and situation awareness. In *Automation and human performance* (pp. 183-202): Routledge.

Imoussaten, A., Montmain, J., & Mauris, G. (2014). A multicriteria decision support system using a possibility representation for managing inconsistent assessments of experts involved in emergency situations. *International Journal of Intelligent Systems, 29*(1), 50-83.

Karagiannis, G. M., & Synolakis, C. E. (2016). *Collaborative incident planning and the common operational picture.* Paper presented at the International Conference on Dynamics of Disasters.

Laakso, K., Palomäki, J. J. T. F., & Change, S. (2013). The importance of a common understanding in emergency management. *Technological Forecasting and Social Change, 80*(9), 1703-1713.

Lelardeux, C. P., Panzoli, D., Lubrano, V., Minville, V., Lagarrigue, P., & Jessel, J.-P. (2017). Communication system and team situation awareness in a multiplayer real-time learning environment: application to a virtual operating room. *The Visual Computer, 33*(4), 489-515.

Luokkala, P., & Virrantaus, K. (2014). Developing information systems to support situational awareness and interaction in time-pressuring crisis situations. *Safety science, 63*, 191-203.

McEntire, D. A. (2002). Coordinating multi-organisational responses to disaster: lessons from the March 28, 2000, Fort Worth tornado. *Disaster Prevention and Management: An International Journal, 11*(5), 369-379.

McNeese, M. D., Pfaff, M. S., Connors, E. S., Obieta, J. F., Terrell, I. S., & Friedenberg, M. A. (2006). *Multiple vantage points of the common operational picture: Supporting international teamwork.* Paper presented at the Proceedings of the human factors and ergonomics society annual meeting.

Militello, L. G., Patterson, E. S., Wears, R., & Ritter, J. A. (2005). *Large-scale coordination in emergency response.* Paper presented at the Proceedings of the human factors and ergonomics society annual meeting.

Norri-Sederholm, T., Joensuu, M., & Huhtinen, A.-M. (2017). *Ensuring Information Flow and the Situation Picture in Public Safety Organisations' Situation Centres.* Paper presented at the European Conference on Cyber Warfare and Security.

Nunavath, V., & Prinz, A. (2016). *Taking the advantage of smartphone apps for understanding information needs of emergency response teams' for situational awareness: evidence from an indoor fire game.* Paper presented at the International Conference on Human-Computer Interaction.

Panagiotopoulos, P., Barnett, J., Bigdeli, A. Z., Sams, S. J. T. F., & Change, S. (2016). Social media in emergency management: Twitter as a tool for communicating risks to the public. *111*, 86-96.

Perry, R. W. (2003). Emergency operations centres in an era of terrorism: Policy and management functions. *Journal of Contingencies and Crisis Management, 11*(4), 151-159.

Schaafstal, A. M., Johnston, J. H., & Oser, R. L. (2001). Training teams for emergency management. *Computers in Human Behavior, 17*(5-6), 615-626.

Seppänen, H., Mäkelä, J., Luokkala, P., & Virrantaus, K. (2013). Developing shared situational awareness for emergency management. *Safety Science, 55*, 1-9.

Sinclair, H., Doyle, E. E., Johnston, D. M., & Paton, D. (2012). Assessing emergency management training and exercises. *Disaster Prevention and Management: An International Journal, 21*(4), 507-521.

Sorensen, L. J., & Stanton, N. A. (2016). Keeping it together: The role of transactional situation awareness in team performance. *International Journal of Industrial Ergonomics, 53*, 267-273.

Steigenberger, N. (2016). Organizing for the Big One: a review of case studies and a research agenda for multi-agency disaster response. *Journal of Contingencies and Crisis Management, 24*(2), 60-72.

van den Homberg, M., Monné, R., & Spruit, M. (2018). Bridging the information gap of disaster responders by optimizing data selection using cost and quality. *Computers & Geosciences*.

Who Learns from Crisis Management Exercises: An Explorative Study

Mari Olsén
Swedish Defence Research Agency
mari.olsen@foi.se

Niklas Hallberg
Swedish Defence Research Agency
niklas.hallberg@foi.se

Kristoffer Darin Mattsson
Swedish Defence Research Agency
kristoffer.mattsson@foi.se

ABSTRACT

Exercises are stated to be an important means to learn how to handle crises. However, it has been discussed who should participate and what can be learnt from them. Several roles are involved in the planning, execution and evaluation of exercises, such as participants, observers, facilitators and evaluators. This paper presents an empirical study of the differences in learning experiences between participants and observers. The study was based on interviews with participants and observers involved in a series of exercises at municipality level. The result shows that the participants' learning relates to individual experiences and how well they felt they performed the task. Meanwhile, the observers' learning experiences concerned organisational issues. The findings suggest that to achieve variation in learning experiences, which is important for inventing new solutions, crisis management organisations need to allow their personnel to try different roles in the exercises to increase the learning outcome.

Keywords

Learning, exercise, crisis management

INTRODUCTION

Crises are events where substantial values are at stake and resources have to be prioritised, commonly with limited situational awareness (Boin, 2009; Borodzicz and Van Haperen, 2002; Sundelius et al., 1997). To be able to manage crises, response systems need to possess a variety of capabilities. In multi-agency contexts, essential capabilities include interaction, relationships, coordination/C2, system performance, preparedness, situation awareness, resilience, decision-making and information infrastructure (Granåsen et al., 2018).

Exercises is a means for societies to develop, maintain and ensure their crisis management capabilities (Borell and Eriksson, 2013). These are typically carried out as multi-agency, inter-organisational exercises, in which several different roles take part in the planning, execution and evaluation. Examples of such roles are participants who will do the training, observers, facilitators and evaluators (Borodzicz and Van Haperen, 2002). During the exercise, the participants carry out the tasks they would perform during an actual crisis, whereas the observers study how the tasks are carried out and how the exercise is executed. Depending on the purpose with the exercise, the participants and the observers learn different things.

Borodzicz and Van Haperen (2002) have argued that facilitators and observers learn from crisis exercises, albeit other things than the actual participants. Participants gain experience and knowledge about their functions, while observers and facilitators gain an insight into how the process works, which is useful to the evaluation and organisational development. In healthcare, Reime et al. (2016) performed a simulation exercise with student nurses, where some of the teams were participants and others were observers. In the study, six learning criteria were defined. The result showed that three of the criteria represented a higher level of learning for participants, whereas in three there was no difference. The observers in the study felt that to gain more confidence in a situation, more hands-on experience was required. Still, one conclusion was that it is important to learn from different roles. Furthermore, in a similar study, Lai et al. (2016) stated that learning effects among participants are not superior

to those among observers, even if their study showed that participation improves the ability to perform the task assigned more, compared to merely observing it. Hence, it has been claimed that observation could be beneficial for gaining more effect from resource-intensive exercises. Studies that relate to this issue have been performed, but there is a lack of empirical studies within the context of inter-organisational crisis management exercises focusing on learning capabilities rather than individual skills.

The objective of this paper is to explore whether there are qualitative differences in learning between participants and observers in crisis management exercises. Furthermore, the objective is to explore what the differences consist of and how they relate to learning, reflective capacity and creativity. The study was performed during a series of crisis management exercises involving the municipalities in the county of Östergötland, Sweden.

BACKGROUND

The process of learning through exercises is important in order to develop crisis management capability. This section presents theories of learning and different types of exercises.

Exercises

Crisis management exercises are proactive events, which are held to strengthen the participants' crisis management capability (Grunnan and Fridheim, 2017). Hence, participation in exercises is a means to strengthen skills and capabilities to handle a crisis.

Different types of exercises have been suggested to increase capability in crisis management. These could be discussion-based (e.g. seminars and workshops), or operation-based (e.g. drills and functional exercises) (Grunnan and Fridheim, 2017). According to Peterson and Perry (1999), tabletop, functional, and full-scale exercises are common types. Collaboration exercises consist of both drills and strategic exercise elements (Berlin and Carlström, 2015). The aim of these exercises is to bring actors together, in order to jointly solve situations by complementing each other's abilities.

Tabletop exercises are discussion-based exercises where the participants examine a given situation (Steward and Wan, 2007). In this form of exercise acting is not required. Instead, the participants discuss how they intend to act (Van Laere and Lindblom, 2018). *Simulation exercises* is a form of tabletop exercise, in which the participants act out their functions in real time according to a scenario. A simulation should reflect reality as closely as possible, so that the participants can experience elements such as time pressure, uncertainty and inadequate information (Borodzicz and Van Haperen, 2002). *Functional exercises* are more complex than tabletop exercises and focus on one or a few functions (Perry, 2004). Focus is commonly on management level and on the coordination between actors and organisation. *Full-scale exercises* are aimed at testing all crisis management functions, including those that represent the "boots on the ground" (Perry, 2004).

Learning

Learning is the process of acquiring knowledge, behaviours, skills, values and preferences, which can be seen as continually ongoing. Learning can be intentional or unintentional, and it can have a wanted or unwanted effect. The theory about learning is extensive, where different ideas and directions are promoted in different research fields, such as educational psychology, neuropsychology, experimental psychology, and pedagogy. In this section, some of the learning theories that are applicable for understanding learning in and from multi-agency, inter-organisational exercises are presented.

Organisational learning is regarded as individual experiences encoded into rules, roles and routines that guide the behaviour of the organisation (Levitt and March, 1988). In this way, knowledge and experiences are maintained in the organisation, even if individuals are replaced over time. Argyris (1977) described organisational learning as single and double loop learning. *Single loop learning* occurs when organisations upgrade their procedures, e.g. due to problems discovered during an exercise. *Double loop learning* occurs when organisations perform more fundamental changes, e.g. changing rules of engagement, business goals or policies.

Experiential learning is the process of learning through experience (Kolb, 1984). It is based on principles originating from ancient times, such as those of Aristotle. Later, Kolb (1984) developed a modern theory of experiential learning based on the work by John Dewey, Kurt Lewin and Jean Piaget. One idea of the theory is to make the participants more involved in their learning. Lewis and Williams (1994) stated that a simple form of experiential learning is *learning by doing*. Participants learn through their own perceived experience followed by reflection. This may result in new skills, new abilities or new ways of thinking. Experiential learning can be carried out as field-based experiences and classroom-based learning. It is held as a powerful and proven approach

for learning, based on the idea that people learn easier through experience. Experiential learning in the form of an exercise is claimed to be an effective tool for learning multiple competencies context (Silenas et al., 2008).

Situational learning takes place in the same context in which knowledge, skills and abilities are applied (Lave and Wenger, 1991). The learning process is ongoing and occurs among individuals engaged in social activities. The learning process is natural and knowledge cannot be separated from the situation.

According to Borodzicz and Van Haperen (2002) and Reime et al. (2016), hands-on experience is important for learning, but the learning outcomes in different roles of participation, for example, observing and teaching, vary. As one crisis is different from another, learning crisis management requires variation. Variation theory in learning implies that an individual could transfer learnings from one situation to another. Through variation in exercise scenarios, it is possible to learn generic skills that could be used no matter what kind of crisis needs to be handled. For example, types of crises are changing (e.g. forest fires and earthquakes), but crisis management systems need to be able to share information, coordinate actions, etc. (Borell and Eriksson, 2013).

Reflective process

Reflection is an important stage in the learning cycle for experiential learning and the ability to learn from exercises (Stainton et al., 2010). When participants have an opportunity to reflect on what happened during or after the exercise, experience transforms to learning. Furthermore, a participant or a team failing to solve a task provides a good opportunity for reflective learning. In these cases, a deeper learning and understanding could be achieved if the reflections focus on how the failure occurred (Stretch, 2000). The reflective process needs to be a critical examination of actions taken. It is easy to say what springs to mind, but the participants must question that thought or the actions that were taken during the crisis or exercise (Lalonde and Roux-Duford, 2013).

Reflection trough debriefing is common in crisis management exercises. The participants often perform this after the exercise. The debriefing process could be guided, video-based, or performed through questionnaires or panel discussions. It has been argued that a structured debriefing process with a significant discussion on what happened is effective for transforming experiences into learning (Borodzicz and Van Haperen, 2002; Kim, 2014).

Creativity

In crisis management, creative thinking is needed in order to apply routines in a different way (Borodzicz and Van Haperen, 2002). Further, creativity that drives innovations is vital for improving practices and organisation changes to better meet a changing environment and conditions (Amabile et al., 1996). Woodman et al., (1993) defined organisational creativity as "the creation of a valuable useful new product, service, idea, procedure, or process by individuals working together in a complex social system". According to Amabile (1998), creativity is based on the three components expertise, creative-thinking skills, and motivation. *Expertise* refers to what individuals know about the issue of interest, whereas *creative-thinking* requires releasing the potential of the mind to come up with new ideas. Creative thinking is based on individuals' attitude toward problems and solutions, together with their skills to amalgamate existing solutions into new combinations to provide new functionalities or capabilities.

METHOD

The present study was based on interviews with participants and observers in a series of crisis management exercises that took place in municipalities in the county of Östergötland, Sweden. Each crisis management exercise lasted for one day and included blocks of different scenarios that were performed as simulation exercises (Borodzicz and Van Haperen, 2002). The scenarios were separate and there was a restart for every scenario. Each scenario lasted for 60-90 minutes. The scenarios included a bus accident involving local students, a car hitting a crowd demonstrating in the centre of the municipality, and flooding in large parts of the municipality, leading to power failure. The exercise included a short period of time for reflections after the scenarios, albeit not in a structured manner. The aim of the exercise was to enhance the municipality's ability to work with crisis management in their organisation according to its assigned routines.

The respondents took part in the crisis management exercise, either as participants doing the training or as observers. For the participants, the exercise was performed in their own organisation. Their training involved functions in the crisis management staff. The observers came from another municipality than the one where the exercise was performed and their partaking was voluntary. They provided an observation protocol for support, the use of which was optional. As the exercise mainly took part in the same room, the observers could observe most parts.

The interviews were conducted by telephone and lasted for 15-30 minutes. As no individual learning goals had been provided for the exercises, the respondents were asked to make a self-assessment of their learning experience. Twelve interviews were performed with participants from six exercises, one to four respondents from each exercise. Of these, four were participants in the training and eight were observers. The interviews were performed in Swedish. Therefore, citations used in this study have been translated into English by the authors. The questions were divided into three sections (Table 1). The interviews started with questions about the participants' experiences, which were described in two ways. First, according to their present functions, if they had other functions in crisis management and how long they had been working with crisis management. Second, in what ways they had taken part in the crisis management exercises, that is, as participants, observers or another role. The second section included questions to the participants who done the training. The questions in this section were about the participants' expectations before the exercise and what they learnt from the exercise. The third section included questions to the observers. The semi-structured questions in this section were about what they had learnt from observing the exercise and if they would have acted differently from the participants. The interview responses were noted during the interview.

Table 1. Interview questions. The questions were asked in Swedish and translated into English by the authors.

Initial questions	Questions to the participants	Questions to the observers
Role in the exercise?	What were your expectations on the exercise and did you practice the things you expected?	What were your expectations as an observer during the exercise?
What is your present function in the municipality?	What did you learn from the exercise?	What did you learn from the exercise? Is there anything you did not learn?
Present experiences in the field of crisis management	What learnings do you bring to future work?	What did you learn that you can bring to your own organisation?
What is your experience of exercises? Participant doing the training, observer, evaluator, facilitator?	How do you expect that the results of the exercise will be used?	Would you have acted differently from those performing the exercise?
		Did you have more time for reflection as an observer than you would have as a participant?

The analysis started with the construction of interview questions to investigate the areas; (1) reflective capacity, (2) dimensions of learning (e.g. individually, team, organisation), (3) earlier experience from crisis management and (4) creativity to find new solutions. The questions were inspired by Borodzicz and Van Haperen (2002).

The analysis of the collected interview responses was performed by two of the paper's authors. Further, the analysis was carried out iteratively, where categories of similar responses were used to form themes. As more data was analyzed the themes were further refined and clarified, resulting in the final set of themes *described lessons*, *reflective capacity*, and *creativity*.

RESULT

The two respondent groups for this study were participants and observers. The participants were trained for their functions in the exercise as chief of staff. In their daily work, they held a position in the administration of the municipality, partly related to crisis management. Two of the observers had been recently employed at the municipality and observed the exercise to gain experience of how crisis management is carried out within municipalities. They had experience of crisis management and response through other organisations such as rescue services and insurance. All of the observers worked with crisis management development and strategies in their own organisations.

Experience from exercises varied, but overall, the respondents had taken part in an exercise more frequently as a participant doing the training rather than as an observer, facilitator or planner of an exercise. In general, those with more experience had both planned and trained in emergency exercises with less need for inter-organisational

collaboration to solve the assigned tasks. Six of the respondents mentioned that they had taken part as a planner or evaluator for their organisation in the most recent collaboration exercise held in Östergötland.

The results are presented according to the participants' and the observers' learning. Finally, the differences in learning between these roles are presented. Learning is described in the areas learning dimensions, reflective capacity, and creativity. Citations from the interviews are used to illustrate the responses.

Participants' learning

The participants in the exercise described their learning based on individual experience, for example, how they practised their own function and how they reacted to the pressure of performing crisis management tasks. One of the participants expressed the importance of feeling secure with the methods that are to be used: *"if you learn them and feel secure with them, you will not feel the same pressure and you can focus even in a stressful situation"*. Another participant wanted to test their learning from earlier education regarding how to act as chief of staff.

The participants had to solve problems during the exercise, which made it difficult to reflect at the same time since the start-up phase was intense. This meant that the participants saved their reflections until they knew the outcome of the scenario and the results of their acting. One observer expressed it as *"valuable to reflect when it is going on [the exercise]. As an active participant you do it afterwards if there is an opportunity, but in these cases it is not as easy"*. However, there were reflections that did not depend on the outcome of the crisis. One of the participants noted the importance of redundancy and replacement of personnel due to exhaustion and tiredness.

Creativity was described as the ability to apply existing procedures in new ways, which might lead to changes in how they are carried out. One example of creativity was described by a participant as *"We have cards that describe our functions in our organisation. I wanted to use them but realised that I chose to do differently to adjust to the situation we had"*.

Observers' learning

The observers described what they learnt from an overview perspective, for example, how to develop methods and train people in their own organisations. One observer described the learning as *"Their staff included decision-makers, which ours does not since it is a separate group. It is another way of working, which we could consider. It would be quicker to make decisions, but at the same time it might disturb the operational work"*. The overview perspective has advantages for organisational learning and development of an organisation.

The observers' reflections included identified differences. These were in some cases based on the observers' own experience. One of the observers stated:

> *I am probably more like the second person and therefore I learnt more from the first one [Referring to chief of staff in the scenarios]. An error that the second chief of staff made, and I realise I always make the same mistake, is to be too involved and take the task assignment from those who really should do them, so that I could have more time for the command and control function.*

Other reflections was made upon the differences that were discovered involved solutions to problems found by the participants and other possible ways of solving them. The solutions mentioned by the observers' mainly concerned internal issues, such as how to work with whiteboards and the allocation of work.

The observers mentioned that the role as an observer gave them more time to reflect on the cases as they did not have to handle the scenario themselves. One of the interviewed observers expressed it as *"If I am taking part in an exercise, I do not have time for reflection. I have to save that for afterwards"*. Instead, the observers had the opportunity to reflect before or in parallel with the progressing scenario. This means that the observers reflected before the outcome of decisions and acting were clear.

To be able to reflect during the crisis management exercises, the observers required knowledge of the system they observed. In their reflections, the observers often related to themselves or to their own organisation. One of the observers also expressed that *"it is important to have knowledge of their work to be able to reflect. It will probably be less valuable if you observe a completely different organisation"*.

Observers are not under the same pressure as participants to solve problems and issues in an exercise. For the participants the task at hand is more important than reflection on their actions, even if it is an exercise. The observers involved in this study could both reflect on how to act in the situation and compare this to how they themselves would have acted. This was expressed by one of the observers as *"the comparison to your own acting is made instantly, but you are not under pressure to act in the situation"*.

In two of the exercises, there was more than one person observing. In these cases, the observers also related their reflective process to the opportunity to discuss with others who made their observations in parallel with the scenario, which was described as positive by the observers.

There were opportunities for the observers to be creative by using an overview perspective to find other solutions to the problems that occurred in the exercise scenario. For instance, one of the interviewed observers pointed out the importance of viewing the situation from an external perspective and concluded that this is easier when observing and not having to focus on a more obvious task, as could be the case for those training. This was expressed as *"it was easier to think from a third person's perspective, for example, with the bus crash. The exercise participants started to act and plan. I could empathise with them and think about how I would have reacted if my son was on the bus"*. Another observer reflected on previous experiences from another crisis organisation, but at the same time concluded that those might not be relevant for crisis management in the observed context.

Differences in learning

The respondents' descriptions of what they learnt in the exercises imply that the participants focused on their own performance and capability to solve the tasks at hand. The observers focused on learnings and development for their organisation, but also their own learning (Table 2).

Table 2. Differences between participants and observers regarding *described lessons*.

Observers	Participants
How to train people in their own organisation	Practice their functions
Discover what types of equipment that could be used, such as whiteboards, maps, working space	Try things learnt from lectures or assessment reports in earlier exercises
Learn about another organisation	How they react under pressure
Roles and mandate of a municipality function	Using their organisation's routines
How they themselves would act in a certain function	
Discover what methods could be used to solve the assigned task	

Even if there is time for reflection after an exercise, there is a difference between when in time reflections are made; during an ongoing event or after the event (Table 3). As the observers in the present study had time to reflect on the situation in parallel with the scenario unfolding, they had opportunities to find alternative solutions to problems the participants did not find due to the pressure of handling the situation. At the same time, the observers had a clearer view of priorities in the scenario and what should be done first to solve the crisis as best as possible. The observers identified lessons applicable to the organisational perspective and lessons for upgrading organisational procedures. By obtaining an overview of the exercise scenario, it is easier to spot processes rather than tasks. Still, the participants' reflections on the applicability of the methods are useful in an evaluation.

Table 3. Differences between participants and observers regarding *reflective capacity.*

Observers	Participants
Make reflections in parallel with the scenario and reflect on different actions without knowing the outcome	Make reflections after the exercise when the outcome of the exercise is known
Make reflections and compare them to themselves or their organisation	Make reflections on their own performance (and in some cases relate these to their organisation)

It was difficult to discover creativity in the interviews and, consequently, differences between the roles (Table 4). Some of the answers indicate that the participants were creative in the way they used the organisations' routines. The observers, on the other hand, were creative in the sense that they found other solutions to the problems that the participants were too stressed to find.

Table 4. Differences between participants and observers regarding *creativity*.

Observers	Participants
Do not need to handle situations and can therefore identify other possible solutions of the problem	Opportunity to adapt the routines in new ways

DISCUSSION

Exercises are an important means to achieve experiential learning, in terms of acquiring knowledge, behaviours, skills, values and preferences (Kolb, 1984). Thereby, exercises can contribute to the development and maintenance of organisations' capabilities, which is also valid within the field of crisis management (Silenas et al., 2008). However, carrying out inter-organisational crisis management exercises is costly and time-consuming. Hence, it is vital to gain the most out of these exercises. One possibility is to explore if other roles than the participants could learn from the exercises. The objective of the study presented in this paper is to explore whether there are differences in learning between participants and observers in crisis management exercises.

The result of this study shows that both participants and observers learn, but that there are differences in their learning. The participants described what they learnt in terms of how they performed during the exercise. They also expected to practice hands-on skills. The participants' learning was experiential in that they were learning by doing. This theory of experimental learning points out the importance of reflecting on an experience to be able to develop new skills and new ways of thinking (Lewis and Williams, 1994). The observers described gaining new insight when relating the performance of others to how they would have acted. The participants raised questions on how they performed, whereas the observers raised questions on how they would perform to achieve an optimal outcome if they were exposed to the same situation. This double loop oriented learning did not give the observers hands-on practise, but prepared them for handling similar situations in the future (Argyris, 1977).

The observers' main lessons learnt were more related to theories about organisational learning (Levitt and March, 1988). This could be due to their purpose as observers, since they wished to develop their own organisation through good examples by others. The observers mainly described their lessons learnt in terms of a possible upgrade of routines and methods in their organisations, rather than learning individual skills. Still, learning individual skills and improving organisations are both important for developing crisis management systems and enhance their capabilities for solving future crises.

Furthermore, the participants reflected on their actions when they knew the outcome of the scenario, which might have hampered any attempts to discover alternative ways of acting. The observers, who made their reflections in parallel with the scenario, evaluated alternatives with a more open mind. Kim (2014) described debriefing as an opportunity to discuss what happened during an exercise and what lessons could be learnt from it. In the studied exercises, no structured debriefing was carried out. However, debriefing sessions could provide a deeper understanding among both participants and observers, i.e. enhance the effect of reflection, due to their different input in the debriefing discussion.

Few interview answers related explicitly to creativity. The exception was examples where participants were creative in applying their routines. Still, creativity is important to effectively solve crises by applying rules and procedures in different ways (Woodman et al., 1993). However, the opportunity to be creative could be limited by the purpose of the exercise, if the aim is to train established crisis management routines. For the observers, creativity might accrue when they initiate the process of applying what they learnt in their own organisation. Still, there are opportunities for creative thoughts even when observing the exercise.

This study had an explorative design. Aspects that might have affected the outcome of the study are, for example, the different purposes for the partaking participants and observers. The aim of the exercise was too test municipality routines. For the observers, the purpose was mainly to find good examples to bring back to their own organisations. However, the results show that there are differences in learning outcomes between participants and observers. The role as an observer provides greater opportunity for reflection and organisational learning. Still, it is important to learn one's own function and how to handle pressure, which the participants pointed out as their lessons learned. As one of the respondents expressed it: *"It is an advantage to observe, but you learn by training also. You learn in different ways"*.

CONCLUSION AND FUTURE WORK

Adequate inter-organisational exercises are challenging and costly to implement. It is, thereby, important to get the most out of exercises. The conclusion of this study is that both participants and observers learn from exercises. Hence, from a financial and time-consuming perspective, it is vital to make use of the fact that others than those

participating learn from exercises. Therefore, exercise management, needs to consider how to create the best learning opportunities for all attendants when planning an exercise. An additional conclusion is that participants and observers learn different things, and they have different possibilities to reflect on events during the exercises. Hence, individuals participating in exercises can learn additional aspects of crisis management and execution of exercises by adopting other roles. As learning through exercises differs between different roles, actors in crisis management exercises need to have the chance to take on different roles to fully grasp all aspects of crisis management. This study was only concerned with what the participants and observers learnt. Future work is needed regarding what other actors, i.e. facilitators and evaluators, can learn.

ACKNOWLEDGMENTS

This paper presents a study carried out within the research project KOMET, sponsored by the Swedish Contingencies Agency. To be able to perform the study the help from the county Östergötland has been invaluable. In addition, we would like to give a warm thankyou to the respondents from the municipalities.

REFERENCES

Amabile, T. M. (1988) A model of creativity and innovation in organizations, Research in Organizational Behavior, 10, 1, 123-167.

Amabile, T. M., Conti, R., Coon, H., Lazenby, J. and Herron, M. (1996) Assessing the Work Environment for Creativity, Academy of Management Journal, 39, 5, 1154-1184.

Argyris, C. (1977) Double Loop Learning in Organizations, *Harvard Business Review*, 55, 5, 115-125.

Berlin, J. M. and Carlström, E. D. (2015) Collaboration Exercises: What Do They Contribute? – A Study of Learning and Usefulness. *Journal of Contingencies and Crisis Management*, 1, 23, 11-13.

Boin, A. (2009) The New World of Crisis and Crisis Management: Implications for Policymaking and Research, *Review of Policy Research*, 26, 4, 367-377.

Borell, J. and Eriksson, K. (2013) Learning effectiveness of discussion-based crisis management exercises, *International Journal of Disaster Risk Reduction*, 5, 28-37.

Borodzicz, E. P. and Van Haperen, K. (2002) Individual and Group Learning in Crisis Simulations, *Journal of Contingencies and Crisis Management*, 10, 3, 139-147.

Borodzicz, E. P. (2004) The missing ingredient is the value of flexibility, *Simulation & Gaming*, 35, 3, 414-426.

Department of Homeland Security (2013) Homeland Security Exercise and Evaluation Program, The Department of Homeland Security.

Granåsen, M., Olsén, M. and Oskarsson, P.-A. (2018) Assessing Inter-organizational Crisis Management Capability - Initial Results of a Systematic Literature Review, *Proceedings of the 15th ISCRAM Conference*, Rochester, NY.

Grunnan, T. and Fridheim, H. (2017) Planning and conducting crisis management exercises for decision-making: the do's and don'ts. *EURO Journal on Decision Processes*, 5, 1-4, 79-95.

Kim, H. (2014) Learning from UK disaster exercises: policy implications for effective emergency preparedness, *Disasters*, 38, 4, 846-857.

Kolb, D. (1984) Experiential learning: experience as the Source of Learning and Development, Upper Saddle River: Prentice-Hall

Lai, A., Haligua, A., Bould, M. D., Everett, T., Gale, M., Pigford, A. A. and Boet, S. (2016) Learning crisis resource management: Practicing versus an observational role in simulation training–a randomized controlled trial. *Anaesthesia Critical Care & Pain Medicine*, 35, 4, 275-281.

Lalonde, C. and Roux-Dufort, C. (2013) Challenges in Teaching Crisis Management: Connecting Theories, Skills, and Reflexivity, *Journal of Management Education*, *37*, 1, 21-50.

Lave, J. and Wenger, E. (1991) Situated Learning: Legitimate Peripheral Participation. Cambridge University Press.

Levitt, B. and March, J. G. (1988) Organizational Learning, *Annual Review of Sociology*, 14, 1, 319-338.

Lewis, L. H. and Williams, C. J. (1994) Experiential Learning: Past and Present, *New Directions for Adult and Continuing Education*, 62, 5-16.

Marton, F. (2006) Sameness and Difference in Transfer, *The Journal of the Learning Sciences*, 15, 4, 499-535.

Perry, R. W. (2004) Disaster exercise outcomes for professional emergency personnel and citizen volunteers,

Journal of contingencies and crisis management, 12, 2, 64-75.

Peterson, D. M. and Perry, R. W. (1999) The impacts of disaster exercises on participants, *Disaster Prevention and Management: An International Journal*, 8, 4, 241-255.

Reime, M. H., Johnsgaard, T., Kvam, F. I., Aarflot, M., Breivik, M., Engeberg, J. M. and Brattebø, G. (2016) Simulated Settings; Powerful Arenas for Learning Patient Safety Practices and Facilitating Transference to Clinical Practice. A Mixed Method Study, *Nurse Education in Practice*, 21, 75-82.

Silenas, R., Akins, R., Parrish, A. and Edwards, J. (2008) Developing Disaster Preparedness Competence: an Experiential Learning Exercise for Multiprofessional Education, *Teaching and Learning in Medicine*, 20, 1, 62-68.

Stainton, A. J., Johnson, J. E. and Borodzicz, E. P. (2010) Educational Validity of Business Gaming Simulation: A Research Methodology Framework. *Simulation & Gaming*, 41, 5, 705-723.

Steward, D. and Wan, T. T. (2007) The Role of Simulation and Modeling in Disaster Management, *Journal of Medical Systems*, 31, 2, 125-130.

Stretch, D. (2000) Simulation Design, *International Simulation and Gaming Research Yearbook*, 8., 33-46.

Stern, E. (1997) Crisis and Learning: a Conceptual Balance Sheet, *Journal of Contigency and Crisis Management.* 5, 2, 69-86.

Sundelius, B., Stern, E. and Bynander, F. (1997) Krishantering på svenska – teori och praktik. Stockholm: Nerenius & Santérus förlag.

Van Laere, J. and Lindblom, J. (2018) Cultivating a Longitudinal Learning Process Through Recurring Crisis Management Training Exercises in Twelve Swedish Municipalities, *Journal of Contingencies and Crisis Management*, https://doi.org/10.1111/1468-5973.12230

Woodman, R. W., Sawyer, J. E. and Griffin, R. W. (1993) Toward a Theory of Organizational Creativity, *Academy of Management Review*, 18, 2, 293-321.

Evaluating the observation protocol of the Team Resilience Assessment Method for Simulation (TRAMS)

Amanda Jaber
Linköping University
amaja463@student.liu.se

Björn J E Johansson
Linköping University
bjorn.j.johansson@liu.se

Linnea Bergsten
Linköping University
linbe360@student.liu.se

Joeri van Laere
Skövde University
joeri.van.laere@his.se

Peter Berggren
Linköping University
peter.berggren@liu.se

ABSTRACT

This work in progress paper presents an initial evaluation of the observation protocol of the Team Resilience Assessment Method for Simulation (TRAMS) conducted in a crisis response simulation project. TRAMS is designed to assess the resilience of crisis response teams. The TRAMS observation protocol uses six core resilience functions from the Systemic Resilience Model as its theoretical foundation. Three independent observers used the protocol during a pilot study and six actual simulation games. Strategies relating to three out of six core resilience functions could be identified. The observations made were distributed similarly among the observers, indicating that the components of the TRAMS protocol are stable enough to continue developing the protocol. This study describes changes made to the protocol since the original design, and describes how the strategies relating to the six core resilience functions can be identified in the simulation games.

Keywords

Simulation games, training, Systemic Resilience Model, team resilience, assessment

INTRODUCTION

How should resilience in multi-organisational crisis response teams be assessed? The increasing complexity of society creates challenges as small disruptions in individual systems may propagate across other systems and create large disruptions. Multiple actors in the financial system provide different kinds of services that jointly create the pre-requisites for services we take for granted, such as credit card payment, online payment, billing, etc. A multi-disciplinary team must thus handle disruptions. The ability to uphold these services is often referred to as *business contingencies* or *resilience*. The payment system can be described as an "inverted pyramid". At the top of the inverted pyramid is the broad base of economic actors whose daily activity in the market economy gives rise to payment obligations. This base of economic actors consists of individuals utilizing retail payment services provided by banks, and a variety of business enterprises in the goods and service industries. The next level includes specialized firms, such as brokers and dealers, involved in the money, capital and commodities market, which also rely on bank payment services. (Blommstein & Summers, 1998, p. 27).

However, the payment system is vulnerable. A cyber-attack or even a bad software update of a common cash register system may cause a nation-wide disruption to the payment system. This issue is being addressed in a project called Creating Collaborative Resilience Awareness, Analysis and Action for Finance, Food and Fuel System in INteractive Games (CCRAAAFFFTING). Reliability in highly networked critical infrastructures has

been studied before, but mostly in the form of case studies (Schulman et al., 2004; Berthod et al., 2017). The goal for this project is to develop a simulation-gaming environment (combining table top role-playing exercises with computer simulation) to present a context where the payment system is represented and where dependencies between different actors in the food, fuel, and financial domains become evident. This approach allows for controlled studies of how resilience is achieved and maintained during disruptions to critical infrastructures (Laere, et al., 2017). The long-term objective of the project is to provide tools and methods for team-training of decision-makers that are responsible for handling crisis situations in multi-organisational contexts. The project will also increase knowledge of how multi-organisational networks manage crises, which is an area in need of further study as pointed out by for example Berthod et al. (2017).

A critical issue in simulation games is the question of how to evaluate them? This paper presents progress in the development of an assessment approach to evaluating resilience in crisis response teams called the *Team Resilience Assessment Method for Simulation* (TRAMS) (Johansson, Laere, & Berggren, 2018). TRAMS was developed for assessing team resilience in simulation games, based on the Systemic Resilience model (see below). The first version of TRAMS was presented at ISCRAM 2018 in Rochester, NY. Since then, a pilot study (with student participants) has been conducted, leading to some minor alterations to the protocol. After that, data has been collected using the TRAMS, which has led to a number of additional suggested changes to the method and the protocol.

The purpose of this work in progress paper is to present the initial evaluation of the Team Resilience Assessment Method for Simulation (TRAMS) based on data from six simulation games. The results will be used to improve the design of the TRAMS observation protocol and create some guidelines in how to use it in future data collections.

The paper begins with an overview of the problem domain (the financial system) and the theoretical basis of the paper, the Systemic Resilience Model. Then, it presents the TRAMS method, the data collection, and the evaluation. Finally, changes to the TRAMS as well as implications of the initial results are discussed.

THEORETICAL BACKGROUND

Resilience is used to describe how a system critical to society, such as industry, infrastructure, finance or ecology, can absorb changes or disturbances and still persist (Holling, 1973; Foster, 1993). Resilience is not to be confused with *robustness*, or stability, which describes how much stress something can take before it seizes to function. It is possible for a system to be robust and lack resilience (Holling, 1973). The financial system is robust when considered over a longer time-period, but also sensitive to local or short-term disruptions that can cause severe cascading effects that have impact even on a global level. It is therefore of great importance to society to improve resilience of the financial system. Resilience has however been interpreted in many different ways (Bergström, van Winsen, & Henriqsen, 2015), making it hard to operationalize resilience into useful strategies and measurable indicators. Lundberg and Johansson (2015) have proposed the Systemic Resilience Model (SyRes) model, in which they have made an effort to merge and compile different points of view in the field of disaster and crisis response resilience. The SyRes model is a way to describe the process, functions and strategies of resilience on a conceptual level in an effort to synthesize different theoretical models and frameworks. The model can be seen as a downward spiral activating certain basic resilience functions and their associated strategies. It is common to divide crisis into three phases: pre-event, event and recovery (before-during-after) (Shaluf, Ahmadyn, & Said, 2003) and the SyRes model applies a similar logic. There are four different sections in the SyRes model: *Event-based constrains, Functional Dependencies, Adjustment of capabilities* and *Strategy* (See Figure 1).

Event-based constraints refer to how the event is handled which put different constraints on the responding system during different phases of the event. Functional dependencies point to the core functions that must be maintained. *These core functions are realized in the form of strategies*, which are depicted on the lower side opposite of the functions in the model. Strategies are in practice the different ways of coping with an event that relate to the core functions. It is common that these strategies are visible in terms of actions taken to keep a system out of harms, for example constructing barriers (immunize) or creating response systems (control). The core resilience functions are: *Anticipating, Monitoring, Responding, Recovering, Learning, and Self Monitoring.*

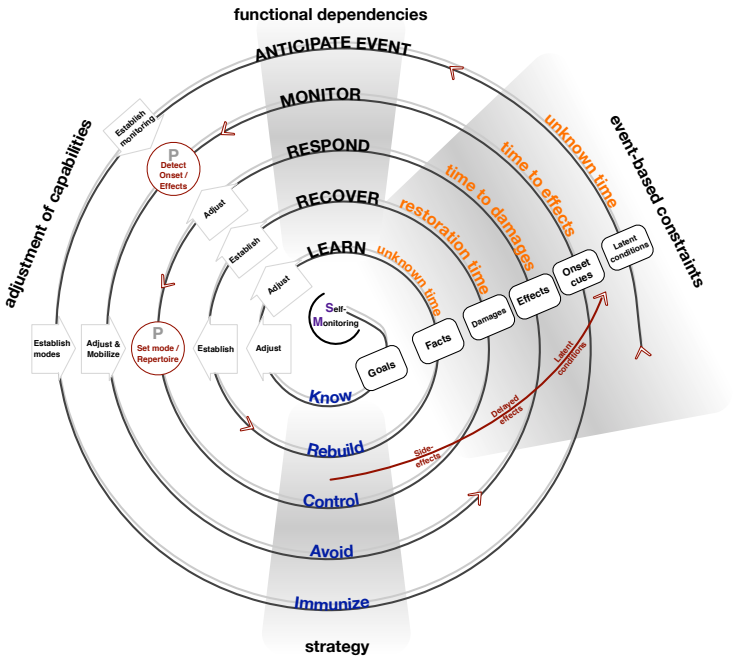


Figure 1. The systemic Resilience Model (Lundberg & Johansson, 2015. Used with permission from the authors).

Each function holds the potential to cope with an undesired development in the *before*, *during,* or *after* phases of a disturbance. For example, if a threat is *anticipated,* it can be mitigated or prevented from happening at all or if *monitoring* is directed in such a way that threats can be detected, harm can potentially be avoided. *Responding* is a consequence of anticipation or the detection of a threat, or even as a reaction to an event that is discovered first when it is already ongoing, and results in strategies for controlling the situation. *Control* is applied to minimize or avoid harm. *Recovery* comes into place when a system takes damage in some form and it needs to re-construct the system after the event. To avoid similar events and adapting ways of working in the future refers to the *learning* steps, which is an essential function to improve the resilience of the system. At last, *self-monitoring* is a continuous process to see if the current way of working is appropriate to maintain an acceptable level of safety and resilience in the system (Lundberg & Johansson, 2015). A lack of resilience manifests when there is a lack of strategies corresponding to the core resilience functions. The TRAMS instrument was created to capture the development of such strategies by teams participating in simulated, multi-domain, crisis response scenarios, hence assessing the capability of resilience of the teams.

Gaming simulation

The interconnected infrastructure in the payment system is experienced through simulation in the CCRAAAFFFTING project. Simulation generally aims at designing a model of a system in a complex problem area in order to perform various experiments (Grune-Yanoff & Weirich, 2010). In this case, the simulation includes a number of grocery stores (ranging from local convenience stores to mega-stores), petrol stations, banks and the flows of goods, fuel, and payments (both cash and by other transfers) that occur between these. The gaming approach is used to gain deeper insight into the behaviour of the participants by evaluating how various resilience strategies relating to the core resilience functions of SyRes (or the absence thereof) are displayed by team members (Laere et al., 2018). It also creates a learning opportunity since the participants are active participants in the simulation and are not just passive observers.

THE TEAM RESILIENT ASSESSMENT METHOD FOR SIMULATION (TRAMS)

As pointed out in the introduction to this paper, the initial TRAMS was presented at ISCRAM 2018. Since then, pilot studies as well as actual data collections have been conducted. **Figure 2**, describes the development process of the TRAMS protocol and method as up until this publication. The TRAMS method, and the process of updating it, is described in detail below.

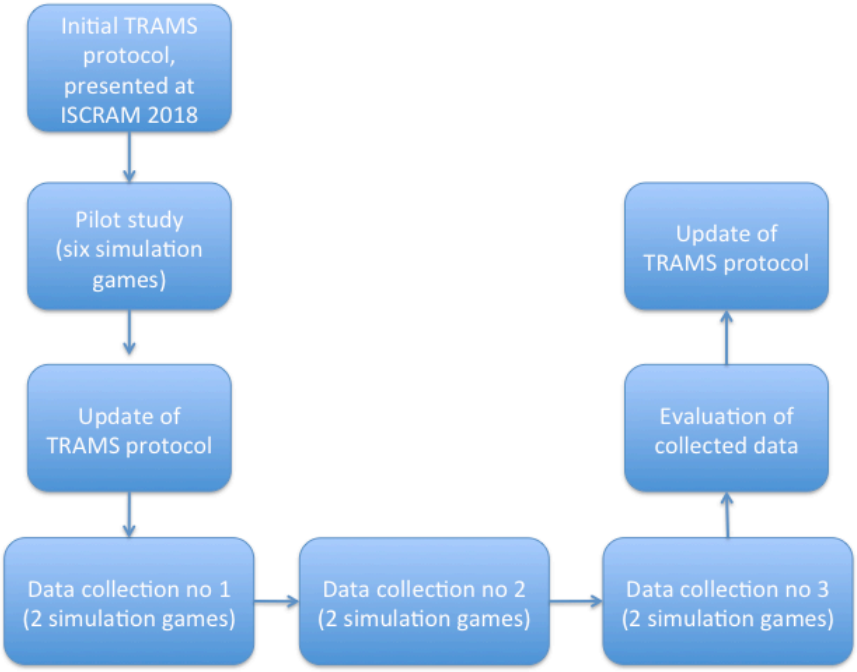


Figure 2. An outline of the TRAMS development process up until this publication.

The approach of the CCRAAAFFFTING project is founded on the premises that stake-holders in society and the financial system that normally don't work together work as a team to manage a disturbance in the payment system. TRAMS is developed evaluate if teams participating in the simulation games are resilient in the sense that they exhibit behaviors, in the form of strategies, that reflect the core resilience functions anticipating, monitoring, responding, recovering, learning, and self-monitoring. The TRAMS instrument comprises several assessments (Johansson, Laere, & Berggren, 2018), such as observations, workload (Helton, Funke, & Knott, 2014; Funke et al., 2012), team trust (cf. Willems, 2016; Seers, Petty, & Cashman, 1995), and shared understanding (Berggren, Johansson, & Baroutsi, 2017; MacMillan et al., 2005) (see **Figure 3**).

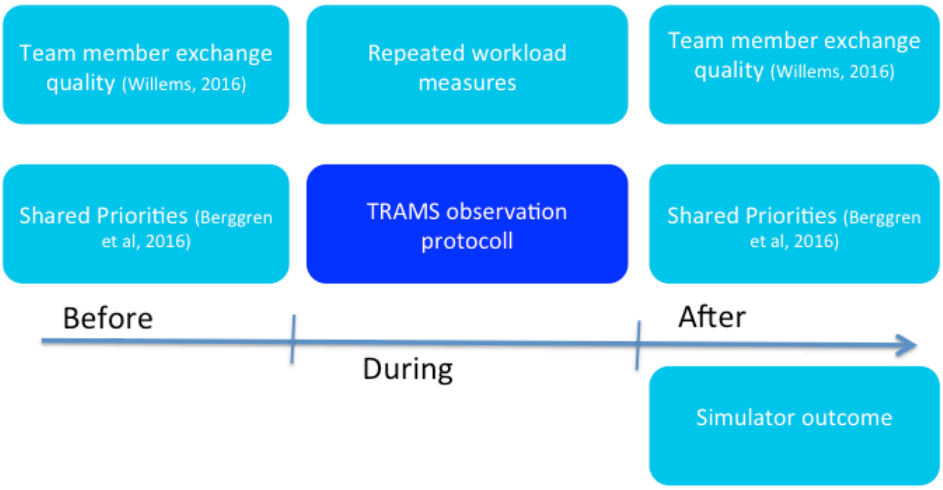


Figure 3. The various assessments of the TRAMS instrument as described in Johansson, Laere, and Berggren (2018). The focus of this paper is the TRAMS observation protocol.

While workload, team trust, and shared understanding are based on established methods, observations are supported by the TRAMS protocol, which is the focus of this paper. Henceforth, *when using TRAMS, and referring to alterations to TRAMS, it is the protocol that is meant*. The protocol, in its original design, consisted of an Excel sheet with the core resilience functions listed on the left-hand side (left column). The protocol is presented in **Figure** 4, followed by a more elaborate explanation of each column.

SyRes functions	Strategies in days 1---N	Developed by…	Core values	Involved actors	Expected effects	Implementation	Simulator outcome
Anticipating							
Monitoring							
Controlling							
Recovery							
Learning							
Self-Monitoring							

Figure 4. The TRAMS observation protocol as described by Johansson, Laere, and Berggren (2018).

SyRes functions

As pointed out, the core resilience functions of the SyRes model can be found in the first column to the left in the instrument. These functions are working as a guidance for identifying strategies that was used by the participants in the simulation during different simulated days of the simulation games. The strategy *anticipating* can take form such as brainstorming, consulting experts, discussing possible consequences of actions under consideration, etc. The strategy *monitoring* is based on earlier experience or actions in the gaming simulation. For example, checking resources or cash flow to understand the disturbance better. The strategy *controlling* is the coping of a disturbance and those actions that are implemented in the gaming simulation. *Recovery* can be based on what is anticipated, currently happening or after a disturbance has happened. For example, if a disturbance is expected in the card payment it can become less severe if all ATMs are prepared with enough cash to support such payments. Strategies relating to *learning* reflect that you learn from the disturbance. For example, creating reporting systems or assuring that experiences made during an event is incorporated in staff training. Strategies relating to *self-monitoring* takes on the form of self-criticism or reflection that alters the way the team works, for example re-organization of responsibilities within the team or changing decision mandates.

Strategies in days 1---N

The fictive days columns reflect the events in the gaming simulation. These are normally known to the researcher/training facilitator and can be described in the instrument. Strategies identified should be noted in the corresponding day. Doing so makes it possible to track what strategies that where developed in the different day. Note that several strategies may be developed in certain days while other days may include no strategies. This depends entirely on the participants and the outline of the scenario used in a particular gaming simulation.

Developed by

This column should be used to describe from whom a specific strategy originates. Was it a collective decision within the team, or did an individual participant suggest it? This information can be used to assess how well collaboration between the different participants work, who (what participant) is taking initiative, and if a certain organization is more prone to pushing strategies.

Core values

This column should reflect the core value that is affected by, or connected to, the strategy observed. This could, for example be revenue of a supermarket, or the well-being of citizens in a municipality. Core values are central to the SyRes model as they are key to the question *resilience of what*, i.e. what the strategies developed actually aims to protect.

Involved actors

The implementation of a strategy will normally involve several actors, both within the participating team and "external" (simulated) actors in the gaming simulation. If possible, these should be noted in this column.

Expected effects

Often, the participants express what kind of effects they believe the strategies they implement will have on the outcome of the gaming simulation. If this can be captured, it should be noted here. This information can be used to analyze what kind of understanding (mental model) the participants had of the scenario and their actions.

Implementation

This column is used to describe if a strategy actually was implemented and if so in what way? In this study it was very clear if the strategies were implemented since the participants needed to write down strategies they wanted to implement and hand these over to the game leader. This also makes is possible to fill in the column afterwards.

Simulator Outcome

The actual simulator outcome of the implemented strategies is noted in this column. This outcome can be used for analysis and the de-briefing session. According to Johansson, Laere, and Berggren (2018) three major performance areas are important, these are: 1) payment options, 2) goods flows, and 3) security.

METHOD

To evaluate, test, and further develop the TRAMS protocol, it was applied in a pilot study, using students as participants, and then on six actual simulation games (out of a planned set of 30 simulation games) with representatives from different stakeholders from society and businesses. In the latter case, three groups played two simulation games each. Three independent researchers applied the protocol when observing the games.

Pilot study

The pilot study was conducted in order to rehearse the procedure of the simulation games, verify that the computer simulation was working, and try the various data collection methods, such as the TRAMS protocol. The data collected was mainly used for verifying that everything worked as imagined. However, the experiences led to some alterations of the protocol. The design, instrumentation, and procedure of the simulation games were identical in both the pilot study and the actual data collection.

Participants

In the *pilot* study, three teams of students and colleagues played the roles of the crisis response teams. Each team consisted of 3-5 participants. The team members had no prior experience of the roles they were assigned to in the simulation games.

In the actual data collection, which is part of the planned 30 simulation games to be conducted, three teams of participants participate. Each team was composed of 6-8 participants from representative businesses, authorities

and public organizations. The *first team* consisted of seven members: one from the fuel distribution sector, two from food distribution (mega-store managers), one from the county administration board, one bank manager, one from the money distribution sector, and one journalist from a local radio station. The *second team* also consisted of seven persons: One from the municipality crisis management team, one from a local convenience store, one from a supermarket, one from the police, one from the money distribution sector, one bank manager, and one from the county administration board. The *third team* consisted of two members from the county administration board, one from the municipality crisis management unit, one grocery store owner, one police, one petrol station manager, one from the money distribution sector, and one bank manager.

As can be seen, the groups were not identical in their composition of competences, but sufficiently representative of the type of individuals that are likely to be involved in a crisis response during a failure of the credit card system.

Instrumentation

The simulation games were audio recorded with Zoom R8 with an Aston Spirit microphone to support note-taking with the TRAMS instrument.

The simulation is implemented and runs on the AnyLogic™ platform. The model uses a Geographic Information System (GIS) space to visualize the locations of food stores, gas stations and ATMs in a region that covers four municipalities (Lund, Malmö, Lomma, and Staffanstorp) in Skåne county, southern Sweden. The total population for the modeled region is 440,000 citizens. Typical shopping behavior is modelled based on available statistics from SCB Statistics Sweden and estimates made by the modeling team (Laere et al., 2018).

Scenario

The scenario describes a crisis in the payment system where card payments go down for ten days. In Sweden, almost all payments are made with cards and many shops even refuse to accept cash. Most people have no preparedness for a breakdown in the card payment system, and the amount of money available in ATMs is not sufficient to support a situation where all citizens needs to pay all their expenses with cash. As pointed out above, the simulation is based on a model of southern Sweden including both a large city and rural areas, is modeled in terms of stores (ranging from small convenience stores to mega-stores) and petrol stations (both manned and unmanned). All transactions, flow of goods, petrol etc. as well as customers and the amount of cash available in ATMs.

Procedure

All participants filled in a consent form and replied to a set of questions about their professional experience as well as experience from actual crisis response events. Then, the background to the CRRAAAFFTTING project was described, as well as the scenario outline for the simulation. After this, the simulation was started. During the simulation game, two researchers were available at all times, ready to answer any questions the participants had about the progress of the simulation or other concerns. The participants in the simulation game takes on the role as a crisis response council that need to suggest actions to handle the situation on days 1, 3, 6 & 9 in the simulation game. They are free to implement a number of things such as introducing new means for payment, providing information to the public, changing the number of security guards or police officers in stores and society, change opening hours of stores or petrol stations, or even close them, etc.

Three observers (denoted A, B, and C respectively) equipped with the TRAMS instrument sat adjacent to the participant team where they could see the participants and the simulation game output. There were no strict guidelines for the observers on how to use the instrument. During the simulation the observers tried utilize as many of the components of the TRAMS instrument as possible. After the simulation games, the observers compared their notes with each other and analyzed similarities and differences.

RESULTS

The pilot study provided valuable input, which led to alterations of both how the TRAMS protocol was used and the design of the protocol in itself. An important observation was that the observers should note only one strategy for each line used in the protocol to avoid mismatches in the number of strategies observed. Observers should also avoid chunking information, meaning that only one strategy should be noted at each occasion. For example, if the participants discussed monitoring sales figures for a specific store and the amount of cash available in the ATM outside the store, this should be noted as two separate observations, not one. Further, the days 1-n was replaced by individual columns in the TRAMS protocol sheet, where each column corresponds to

a decision event, i.e. days 1, 2, 3, 6, & 9.

Data from the actual data collection found strategies relating to three of the six core resilience functions; *anticipation, controlling,* and *self-monitoring*. The strategies *recovery* and *learning* were not observed during the game simulation.

The average distribution of observations over categories of strategies noted by the three observers A, B and C (percentage of the total amount of observations by each observer) from all six simulation games is found in **Table 1**. A criterion was used in order for a category of strategy to be included in the analysis: at least two observers would have to have noted the same strategy. Hence, learning is not included in the analysis as only observer B identified that. This is discussed further below.

Table 1. Average distribution of observed strategies in each category by each observer and the average total (in percent of the total amount of observations by each observer).

	Observer A	Observer B	Observer C	Total average
Anticipation	73.9%	64,2%	73,9%	70,7%
Monitoring	0,9%	7,4%	0,2%	2,8%
Controlling	25,3%	24,4%	25,2%	24,9%
Recovery	0%	0%	0%	0%
Learning	0%	0,3%	0%	0,1%
Self-Monitoring	0%	3,9%	0,6%	1,5%

On average, the observers made 109 observations per simulation game (Observer A=114, Observer B=111, Observer C=103). As can be seen in **Table 1**, and from the average number of observations conducted by the observers, the inter-observer consensus regarding what strategies were used in the simulation games is good. These numbers should be interpreted with some caution given the fact that they are based on only six simulation games.

Strategies relating *anticipation* were the most common of the observed strategies during the six simulation games. Strategy was identified during the game when the participants were talking about a potential development in the simulation, a consequence of the development, or the potential consequence of an action but did not go through with it. This type of reasoning was by far the most common during the simulation games. In essence, the participants were collectively discussing various hypotheses about what would happen during the simulation game and how their own action potentially could affect this development. It could for example be if they wanted to implement alternative means of payment early in the first day, but they never implemented it in the simulation. Other common topics were if customers would start hoarding products, whether there would be enough money in the ATM's, and the effects of information to the public – would it lead to increased attempts to buy things, or decrease them? Another example is when participants are worried about the stores' stock but did not check this against the simulation or did anything about it. In summary, the strategy anticipation is applied when the participants discuss and brainstorm potential actions and developments and think about important aspects to solve the disruption problems, but they don't implement them in the simulation game or check it in the game, at least not at the same game-day as the discussion takes place.

Strategies relating to *monitoring* were only classified a few times by the observers. On rare occasions, the participants in the simulation game asked the researchers running the simulation model about the state of specific parameters in the simulation game. In all such cases, they were given feedback. At some occasions, the participants also asked about the underlying logic in the model on which the simulation is based. Examples of monitoring are questions about the amount of money in ATMs, the number of citizens that are hoarding, or what kind of behavioral model that was used for customer behavior.

Strategies relating to *controlling* were the second most common in the observed simulation games (see **Table 1**). This is not surprising as the participants were asked to describe what actions they would like to have implemented on days 1, 3, 6, & 9 in the simulation game. Typically, they performed actions such as adjusting opening hours of stores, fill up the ATMs with cash, introduce alternative payment methods, and provide information to the public about the state of affairs and suggested actions to citizens. Controlling actions generally focused on minimizing the consequences of the payment disruptions, both in terms of lost incomes of business owners and from a community perspective.

Strategies relating to *recovering* were not observed during the simulation games. The main reason for this is

probably that the participants interpreted the task of the scenario as dealing with the foreseeable and immediate consequences of the disruption. Recovery as such was thus not yet necessary.

Strategies relating to *learning* were observed by only one of the observers (Observer B) and are therefore not counted in this assessment. The lack of strategies relating to learning can partly be explained by the fact that the simulation game was seen as an exercise, and learning may have been interpreted as something that will take place after rather than during the simulation game.

Strategies relating to *self-monitoring* were observed at a few occasions. Examples of this are when participants begin to discuss whether the way they are organizing their work or begin to question if the approaches they adapt are viable or not.

MODIFICATIONS TO THE TRAMS PROTOCOL AND METHOD

The data collection conducted resulted in some alterations to the initial TRAMS protocol and method. The TRAMS protocol was updated (see Figure 5) after the first simulation game. The new version of the protocol has some changes from the first version (Johansson, Laere, & Berggren, 2018) since it was noticed that it was not possible to use all components included in the original version. The most important change is that, *core values* no longer are used because it was hard to assess them during the observations. It is recommended to have at least two observers using the TRAMS protocol and have them compare the outcomes with each other. A single annotator will need to have experience in identifying the strategies and note taking. Furthermore, in some situations it is difficult to correctly assess what is happening, especially if the team enters parallel discussions. In such cases, it may be necessary to go back and listen to the audio recordings to capture what actually was discussed

DISCUSSION

Subjectivity of the involved observers obviously plays an important role as observations may be connected to the strategies differently. However, the results indicate a good coherence among the observers in this limited data collection, although the collected material was too small to calculate inter-rater reliability.

Only three of the six core resilience functions could be related to observed strategies, *anticipation, monitoring* and *controlling*. This may be due to the limitations of the game simulation, the participants or other factors. It is likely that it depends on that the participants have not had time to train enough. Alternatively, *learning* may not be visible during the games themselves. Hopefully, further studies can clarify this, because it does not mean that *controlling* and *learning* cannot be found just because it was not seen in this data collection. Also, the core values could not be assessed. The original version of the protocol had core values as an own column, but this study did not find these during the games and could not find any practical utility with it in the observation protocol.

As pointed out in the results section, it is at times hard to keep up the note taking during the gaming simulation and at least two observers are probably needed. An advantage of using two observers is also that it is possible to compare observations with each other after the game. Audio recording is also important, both as a support for verifying observations and as an important data set for retrospective analysis. Some cons are that we could not fill in the core values since our knowledge about the participants' core values was too low and it was difficult to use it during the game simulation.

The fact that only three categories of strategies relating to the six core resilience functions were found in the simulation games is interesting. Of these three categories, anticipation was clearly the most common, followed by controlling. Monitoring was only observed at a few occasions. Table 2. shows the distribution of the observations. It is not clear from the observations or experiences from the simulation games why the distribution looks in this way, but we have two main hypotheses: 1) that the teams get so engaged in their discussions about possible developments (anticipation) that they simply forget to ask the simulation managers about the actual state of affairs in the simulation (monitoring), and, 2) that the current game design, where the participants are asked to make decisions at certain points in time (simulation game days 1, 2, 3, 6, & 9) creates a situation where the participants believe that it isn't necessary to ask for additional information between these decision-points.

SyRes functions	Strategies days 1	Strategies days 2	Strategies days 3	Strategies days 6	Developed by…	Involved actors	Expected effects	Implementation	Simulator outcome
Anticipating	Put in security early?								
		Prepare billing opportunities and swish?			All	Banks, stores, transport		Yes	
			Lower the price of products that are going to go bad?		Store	Store			
Monitoring		Check how much money there are left in the stores			All	Store		Yes	Not that bad yet
				Check how it works with swish, invoice and money in the stores	All	Payments and disappointed costumers	Get an overview	Yes	Relatively good
Controlling	Inform the costumers that disruption is happening?				All	Costumers		Yes	Good effect
	Close the stores				All	Stores		Yes	Good effect
		Refill the ATMs with money			All	Banks		Yes	Small effect, but still not that bad yet
Recovery									
Learning									

Figure 5. Example of how the TRAMS protocol can be populated during a simulation game.

CONCLUSION

In conclusion, the TRAMS protocol has been modified to better support observations of resilience strategies used by the teams to cope with the disruption in the gaming simulation. The instrument is yet not fully developed and there are still columns that need to be added or deleted before it can be validated, but it is a first try to structure a data collection based on the SyRes model. The TRAMS method has so far been successfully applied to six out of a planned series of 30 simulation games. The result led to a guide and examples on the strategies *anticipation, monitoring* and *controlling.* Strategies relating to the core functions *recovery, learning* and *self-monitoring* were not found in this study. The discussion above suggests two hypothetical causes for this: 1. The style of the participants in the particular simulation games studied, and, 2.) that the design of the simulation game not encourage the formulation of strategies relating to these core resilience functions. The instrument will be continuously developed along with the simulation game approach during the following 24 simulation games. Experiences from these simulation games will help mature TRAMS until it is a validated and mature research instrument.

ACKNOWLEDGMENTS

This research was supported by Grant 2016-3046 of the Swedish Civil Contingencies Agency.

REFERENCES

Berggren, P., Johansson, B. J. E., & Baroutsi, N. (2017). Assessing the quality of Shared Priorities in teams using content analysis in a microworld experiment. *Theoretical Issues in Ergonomics Science* , 18 (2), 128-146.

Bergström, J., van Winsen, R., & Henriqson, E. (2015). On the rationale of resilience in the domain of safety: A literature review. *Reliability Engineering and System Safety*, *141*, 131–141.

Blommstein, H.J. and Summers, B.J. (1998). Banking and the payment system. In: Summers, B.J. (Ed.), *The Payment System – Design, Managmenet and Supervision*. International Monetary Fund, Washington D.C., 15-29.

Berthod, O, Grothe-Hammer, M., Muller-Seitz, G., Raab, J., & Sydow, J. (2017). From High-Reliability Organizations to High-Reliability Networks: The Dynamics of Network Governance in the Face of Emergency. *Journal of Public Administration Research And Theory,* 352-371.

Foster, H. D. (1993) Resilience Theory and System Evaluation. In (Eds.) J. A. Wise, V. D. Hopkin & P. Stager, *Verification and Validation of Complex Systems: Human Factors Issues*. *(pp. 35-60)* Springer Verlag: Berlin.

Funke, G. J., Knott, B. A., Salas, E., Pavlas, D., & Strang, A. J. (2012). Conceptualization and Measurement of Team Workload: A Critical Need. *Human Factors* , 54 (1), 36–51.

Grüne-Yanoff, T. & Weirich, P. (2010) The Philosophy and Epistemology of Simulation: A Review *Simulation & Gaming*, 41, 20–50.

Helton, W. S., Funke, G. J., & Knott, B. A. (2014). Measuring Workload in Collaborative Contexts: Trait Versus State Perspectives. *Human Factors*, 56 (2), 322–332.

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics. 4,* 1-23.

Johansson, B. J. E., Laere, J. van, Berggren, P. (2018). Evaluating Team Resilience in Simulator-Based Crisis Management Training. *ISCRAM 2018,* Rochester, NY, 20–23 May.

Johansson, B.J.E., Laere, J., & Berggren, P. (2018). Evaluating Team Resilience in Simulator-Based Crisis Management Training. *ISCRAM 2018*, Rochester, NY, 20-23 May.

Laere, J. van, Berggren, P., Gustavsson, P., Ibrahim, O., Johansson, B. J. E., Larsson, A., … Wiberg, C. (2017). Challenges for critical infrastructure resilience: cascading effects of payment system disruptions. In *ISCRAM 2017* (Vol. 2017–May). Albi, France.

Laere, J. van, Berggren, P., Ibrahim, O., Larsson, A., & Kallin, S. (2018) A simulation-game to explore collective critical infrastructure resilience In: *Safety and Reliability – Safe Societies in a Changing World: Proceedings of ESREL 2018*, S. Haugen, A. Barros, C. van Gulijk, T. Kongsvik, & J. Vinnem (eds.) pp. 1305–1312. CRC Press, Trondheim, Norway.

Lundberg, J., & Johansson, B. J. E. (2015). Systemic resilience model. *Reliability Engineering and System Safety*, *141*, 22–32.

MacMillan, J., Paley, M. J., Entin, E. B., & Entin, E. E. (2005). Questionnaires for Distributed Assessment of Team Mutual Awareness. In N. Stanton, K. Hedge, E. Brookhuis, E. Salas, & H. Hendricks (Eds.), *Handbook of Human Factors Methods* (pp. 51–1–51–9). London: Taylor and Francis.

Schulman, P., Roe, E., Eeten, van M., & Buijne de M. (2004). High Reliability and the Management of Critical Infrastructures. *Journal of Contingencies and Crisis Management*, 12 (1), 14-28.

Seers, A., Petty, M. M., & Cashman, J. F. (1995). Team-member exchange under team and traditional management. *Group & Organization Management*, 20 (1), 18–38.

Shaluf, I. M., Ahmadun, F., & Mat Said, A. (2003). A review of disaster and crisis. *Disaster Prevention and Management: An International Journal*, *12*(1), 24–32.

Willems, J. (2016). Building Shared Mental Models of Organizational Effectiveness in Leadership Teams

Through Team Member Exchange Quality. *Nonprofit and Voluntary Sector Quarterly*, 45 (3), 468–492.

Design to Fit – Morphological Analysis as a Tool for Exercise Design

Pär Eriksson
Swedish Defence Research Agency
par.eriksson@foi.se

Niklas Hallberg
Swedish Defence Research Agency
niklas.hallberg@foi.se

ABSTRACT

Exercises are considered as vital to develop and sustain crisis management capabilities. An exercise may have a role both as a provider of knowledge about the crisis management system, and its performance, and as a driver of change through training of individuals, groups and organizations. However, the relationship between the design and characteristics of a specific exercise, and the usability of its results in the development of the crisis management system is not well-understood. The objective of this paper is to explore if a morphological field can be used to investigate this relationship. Such a field was designed and evaluated. Even though this field was relatively simple, it was concluded that it provides results that deepen the understanding of how different types of exercises can contribute to the development of the crisis management system.

Keywords

Exercise design, morphological analysis, crisis management.

INTRODUCTION

A crisis is a situation where substantial values are at stake, characterized by severe urgency and a high degree of uncertainty (Boin, 2009; Sundelius, Stern and Bynander, 1997). Generally, crises are events that falls outside of the affected organizations' normal spectrum of challenges, something that distinguish crises from emergencies (Borodzicz and van Haperen, 2002; Lagadec, 2009; Wybo, 2004).

Examples of crises include natural disasters such as the tsunami in south-east Asia in 2004 and the forest fires in California and Greece in 2018, large-scale terrorism such as the ones in New York and Washington 2001 and in Paris 2015, and man-made environmental catastrophes such as the gas leak in Bhopal 1984 and the catastrophic nuclear accident in Chernobyl 1986. Crises, as opposed to emergencies, are rare and as a consequence there are relatively few relevant experiences available from actual events. However, their character and their consequences, as well as the strategies for handling them, are difficult to visualize in advance (Lagadec, 2009; OECD, 2015).

Crisis management generally involves a large number actors with different characteristics, roles and objectives (Comfort, 2007; Doyle, Paton and Johnston, 2015; Eriksson *et al*, 2017). The crisis management structures needs to be agile and adapt its configuration and response to fit a specific crisis (Boin, 2014; Comfort, 2007; Kim, 2014). Furthermore, as threats and vulnerabilities continuously change, so must the crisis management structures.

Exercises are considered vital to develop and sustain appropriate crisis management capabilities (Beerens and Tehler, 2016; Berlin and Carlström, 2015; Borrel and Eriksson, 2013; Kim, 2014, 851; MSB, 2016, OECD, 2015). Exercises have two overarching roles from this perspective: (1) to provide actors with new knowledge and competences or to validate existing knowledge, i.e. learning from exercises and (2) to be a driver of change through the training of actors, i.e. learning in exercises.

Multi-agency, inter-organizational exercises involve two or more organizations, possibly with some actors simulated, or one organization where the actions and reactions of all other organizations are simulated. These exercises may have different types of formats, such as table-top, functional or full-scale. Furthermore, they may also have different types of objectives, such as training, evaluating, or exploring. Training exercises aim at increasing the ability of individuals or organizations through the implementation and training of plans, procedures and methods, while evaluating exercises test current plans, procedures or methods or the ability to use them. Explorative exercises aim at finding new ways of handling challenges, e.g. through testing of new methods.

Multi-agency, inter-organizational exercises can be described using a number of different types of dimensions, such as the exercise format, the participants' level of experience, and the size and character of the exercised event. These exercise are furthermore complex and expensive endeavours, and the number of actors participating, with their different roles, their different types of organizations, and their different objectives represents a considerable challenge. It is therefore crucial to ensure that the exercises are designed so that resulting observations and conclusions are valid for the planned development process. However, the relationship between the design and characteristics of an exercise, and the usability of its results in different types of development efforts is not well studied. There is a need for developing ways to discuss this relationship in a structured way.

Morphological analysis can be used to investigate multidimensional problems with several possible solutions and different stakeholders (Ritchey 2006). The objective of this paper is to explore if a morphological field can be used to investigate the relationship between the characteristics a specific exercise and the usability of its results in different types of development efforts.

BACKGROUND

The crisis management structures could be regarded as a continuously developing system, having a configuration consisting of, for example components, goals, culture, rules, and procedures. This configuration is, using the terminology of Argyris and Schön (1996), the crisis management system's *theory-in-use*, i.e. a representation of the knowledge guiding an organization's activities and how these are performed.

If new knowledge leads to changes in the structure of the system's configuration, this is a change in the theory-in-use, or what Argyris and Schön (1996) call *double-loop learning*. Knowledge that instead leads to efforts for the incremental increase of the quality of existing parts of the configuration, is on the other hand called *single-loop learning*. Not all changes in the configuration are, however, double-loop learning. To exchange a system component with another one that does the same thing, albeit more efficiently, is single-loop learning, since the basic configuration remains the same and no change in the structure of theory-in-use has occurred.

Morphological analysis can be used to structure, and tame, so called wicked problems (Ritchey, 2006, 2011). Wicked problems are complex problems that involve several different stakeholders and perspectives, consist of several different dimensions that are interdependent in entangled manners, and include political and social complexities. Furthermore, these problems have no single correct answer, and what is seen as a good or acceptable solution will remain in the eye of the beholder. Wicked problems are genuinely difficult to define and every wicked problem is essentially unique. (Peters, 2017; Ritchey, 2011) Two examples of wicked problems are climate change and prioritization of communications infrastructure.

Although morphological analysis was proposed and used by Fritz Zwicky already in the 1940s, the use of manual calculations limited its usability. However, with the help of modern computers and software, also quite large morphological fields can be analysed (Ritchey, 2006).

The core idea in morphological analysis is to identify the relevant dimensions of the problem, and then assign mutually excluding and, in the context of the problem, exhaustive values to each dimension. The resulting morphological field can be used to explore different combinations of values from the different dimensions. As an illustrative example, a morphological field for choosing means of transportation when commuting to the city centre from a suburb, taking into account the dimensions of budget, commuting time, and environmental footprint, is presented in Figure 1.

Budget (per month, USD)	Acceptable commuting time (single journey)	Type of transportaton	Acceptable environmental footprint
<25	<20 min	Walk	Zero
<100	<60 min	Bike	Low
<1000	>60 min	Subway	Medium
		Car	High

Figure 1. A morphological field for the choice of transportation.

This morphological field contains 144 potential combinations of the values (rows) in the four dimensions (columns). Some of these combinations are feasible, for instance, the one highlighted in Figure 1. Others are not, for instance any combination of walking and less than 20 minutes of commuting time. In this simplified example it each potential combination can easily be manually examined. However, since a typical morphological field may consist of 10 000 potential combinations or more, manual analysis is not an option.

Instead software tools for morphological analysis are used to perform pairwise comparisons to decide which values

that can co-exist. Then the software identifies all combinations of values that are possible. If the original research question is well-defined and the morphological field is well-designed, the remaining number of combinations will be manageable.

In the commuting example, an environmental footprint that is zero can only co-exist with the values of walking or biking (Figure 1). Walking and biking are also the cheapest alternatives and can co-exist with all the values for the dimension budget. Instead of manually analysing the 144 different combinations of values to identify which ones are possible, the manual labour is reduced to do 73 pairwise comparisons, and then the software identifies the possible solutions. This difference in effort grows with increased complexity. Just adding one more dimension, with three values, would increase the number of combination that needs to be analysed to 432, but leave the number of pairwise comparisons at 109.

METHOD

To explore if a morphological field can be used to investigate the relationship between the characteristics a specific exercise and the usability of its results in different types of development efforts we used a tool for morphological analysis called CASPER (Computer Aided Scenario and Evaluation Routine) developed at the Swedish Defence Research Agency. The morphological field was developed in three phases: (1) setting a focus question, (2) developing a draft morphological field, and (3) conducting pairwise comparisons of values. In the first phase, the following focus question was chosen:

- What aspects of an exercise will affect how the results and lessons from the exercise can be used to change the crisis management system?

In the second phase, the morphological field consisting of dimensions and their values was developed. Normally this is done by using a group of subject area specialists, often practitioners (Ritchey, 2011). In this case, a draft field was first developed by the author. This draft field was then discussed, revised and improved by a group of six researchers and analysts with considerable experience from the areas of exercises and crisis management.

Designing a morphological field is often an iterative process (Ritchey, 2011). In this case, the field was further revised and developed during the pairwise comparisons. These revisions included both structural changes such as introduction of new values and removal of dimensions, and clarifications such as the inclusion of explanatory texts in some dimensions and values. However, for the sake of clarity the process is here described as linear rather than iterative.

The third phase was the pairwise comparisons, which were carried out using the same group of researchers and analysts that designed the morphological field. Normally the pairwise comparisons, like the design of the field, are carried out by a group of subject matter experts. However, as was the case with the design of the morphological field, it was decided that for the purpose of this study that the researchers and analysts had sufficient experience of planning, conducting and evaluating exercises.

The process of comparisons took about 10 hours of group work. Given that the group was quite homogenous, this was slightly more than had been expected. However, it was considered important to let the process run its course without forcing it, to ensure a reasonably stable result.

After developing the morphological field, it was tested in a series of analyses. In a first step the possible combinations of dimensional values related to each value in the output dimension were investigated. As a second and slightly more complex step, combinations of different values, representing features in common types of exercises, were tested against the output values.

RESULTS

The results of the process was the dimensions and values that constituted the morphological field, the outcome of the pairwise comparisons, and the conclusions from the evaluation of the field developed.

The Dimensions and Values in the Morphological Field

The morphological field consists of nine dimensions: (1) types of development efforts (in which to use the results from the exercise), (2) exercise format, (3) exercise objectives, (4) exercise planning logic, (5) exercise participants, (6) exercise focus (level), (7) exercise focus (content), (8) size and character of event and (9) frequency of exercises.

Types of development efforts (in which to use the results from the exercise)

The objective of the dimension *types of development efforts (in which to use the results from the exercise)* was to describe the output dimension of the morphological field, i.e. what types of system development efforts that the lessons and observations from the exercise should support. It was defined by four values: (1) develop exercise methodology, (2) increase the capability in the current crisis management system, (3) develop the current crisis management system and (4) transform the current crisis management system into something new, outside the current paradigm.

In the discussion, it was noted that the first value, to *develop exercise methodology*, was compatible with all the values in the other dimensions and consequently yielded no further information. Hence, in order to reduce the size of the morphological field, this value could have been deleted, without decreasing the model's analytical strength. Nevertheless, this value was kept in the field as a record since as it was concluded that in a future, more refined analysis it can have analytical significance.

The latter three values correspond to the different variants of single-loop and double-loop learning. *To increase the capability in the current crisis management system* is related to single-loop learning where the ability to use current methods, procedures or technologies is increased. *To develop the current crisis management system* is also related to single-loop learning, when single components are exchanged but the basic structure remain. *To transform the current crisis management system* is, on the other hand, related to double-loop learning, where exercise leads to changes in the structure of the system's configuration.

Exercise Format

The objective of the dimension *exercise format* was to describe the possible formats in inter-organizational exercise. It was defined by four values: (1) table-top exercises (2) functional exercises (3) full-scale exercises with one actor and the others simulated and (4) full-scale exercises with several actors.

The group defined the format *table-top exercises* to include a wide variety of discussion based exercises, from seminars where a group of participants meet and use a scenario to discuss a common problem to an exercise where all participants acts in their normal roles. Inter-organizational *functional exercises* were regarded as exercises involving one function, for instance crisis communication to the public or logistics, from several different organizations. *Full-scale exercises* were regarded as exercises where the actors participate also with operational resources. However, it was noted that, depending on the exercise objectives, a full-scale multi-agency inter-organizational exercise could consist of either several organizations or one organization and the others simulated.

This dimension could be further developed in future fields, for instance by using more detailed descriptions of the exercise formats. However, for the purpose of studying whether a morphological field could be used to describe the relationship between the type and character of an exercise and the usability of its results in the development of the crisis management system, the group decided that the chosen level of detail was good enough.

Exercise Objective

The objective of the dimension *exercise objective* was to describe the main purpose, implicit or explicit, of the exercise. It was defined by four values: (1) Train/educate, (2) test/evaluate, (3) explore/develop and (4) to signal capability internally or externally.

In the discussion it was noted that these values are not necessarily mutually excluding. For instance, there could be considerable training effects in an exercise primarily designed to test a system or its capabilities. Furthermore, many times two or more objectives need to co-exist, since there is a limited number of exercises. While the first three values are common in the literature, the fourth is more rarely found. However, from the experience of the group, this type of objective is present, explicitly or implicitly, in many exercises.

Exercise Planning Logic

The objective of the dimension *exercise planning logic* was to describe the underlying logic in the planning of the exercise. It was defined by two values: (1) scenario driven and (2) capability driven.

In the discussion, it was noted that a scenario driven exercise is when the scenario constitutes the starting point of the planning. Such exercises will focus on a specific chain of events. A capability driven exercise, on the other hand, is when the scenario is just a tool and the main focus is instead on the specific capabilities to be used. The basic difference between these two planning logics is the underlying principle. In the first case, you prepare the system to be able to handle specific scenarios that for one reason or another are seen as specifically probable, dangerous or interesting, and in the second case, you prepare the system's individual capabilities for any type of

crisis. The latter is sometimes called *zombie apocalypse planning*, alluding to the use of scenarios that, although highly unlikely, represents considerable challenges for the capabilities in focus.

Exercise Participants

The objective of the dimension *exercise participants* was to describe the level of experience among the exercise participants. It was defined by four values: (1) novice/beginner, (2) competent professional, (3) skilful/master professional and (4) experts/academics.

In the discussions, it was noted that most exercises include a mix of participants possessing different skill levels, from the novice to the master. However, the participants' level of experience was seen to affect not only how exercises can be designed and implemented, but also the validity of exercise results as well as their usability in different types of development processes.

It was decided to use a simplified version of the classification introduced by Dreyfus and Dreyfus (Dreyfus and Dreyfus, 1980; Tillberg and Tillberg, 2013) since it is based on a notion of the individual's competence and ability. The first value is *novice/beginner*. A *novice* is a professional who is completely new to the assigned task and a *beginner* is a professional with some, but limited, experience that is only able to follow simple instructions. The next value is *competent professional*, which is a professional who has gathered enough knowledge and experiences to be able to act independently and who may learn new similar tasks with instructions. The third value is *skilful/master professional*, which is able to act independently and, in the case of a master, almost intuitively making decisions simultaneously with assessing the situation. Finally, the group found that in some exercises *experts/academics* are used as participants to test and evaluate methods and plans from a scientific standpoint, and it was decided to add this as a fourth category to the ones defined by Dreyfus and Dreyfus. Although most exercises will have a mix of participant categories, for the purpose of this study it was deemed enough to choose the dominating one. In future studies, a more detailed approach can be tested.

Exercise Focus (Level)

The objective of the dimension *exercise focus (level)* is to describe *what decision-making level* that the exercise focuses on. It was defined by three values: (1) strategic, (2) tactical and (3) operational.

In the discussions this was the most complex dimension. Firstly, there are several different typologies for describing these levels (gold, silver, bronze; strategic, tactical, operational, etc) and they are not unequivocally described. Secondly, most inter-agency exercises involve multiple levels.

In the end, the above three values were used, as they are common among practitioners and to some extent are intuitive also for non-practitioners. The discussions concluded that the *strategic level* is the level where decisions are made regarding the overall objectives and prioritizations in the crisis, while the *tactical level* is the level where decisions are made regarding the choice of operational methods and prioritizations. Finally, the *operational level* was seen as the level where decisions are made to implement and lead the crisis management operation on the ground. In addition, a value of *multiple levels* was added for the case where no single level can be seen to dominate as this was found to be very common in multiagency inter-organizational exercises.

Exercise Focus (Content)

The objective of the dimension *exercise focus (content)* was to describe *what types of abilities* the exercise focuses on. It was defined by three values: (1) skills, (2) methods, plans and procedures and (3) concepts and generic capabilities.

This dimension generated a lot of discussions in the group, as the definitions of the values were all but straightforward. A complicating fact was that the values should be applicable on activities at different levels and, furthermore, be meaningful to different types of activities.

In the end, *skills* were seen as individual abilities, such as the ability to carry out a specific firefighting action or the ability to make a strategic decision. *Methods, plans, and procedures* were regarded as organizational rules and routines controlling the activities, for instance the existence and quality of procedures for handling a specific firefighting situation, or the existence and quality of a strategic plan for the handling of a flooding. Finally, the value *concepts and generic capabilities* was considered to represent the overall conceptual level that is definitions of the overarching priorities and choices, including the need for generic capabilities such as the capability to coordinate and the capability to communicate.

Size and Character of Event

The objective of the dimension *the size and character of crisis event* was to distinguish between exercises focusing on events that lie within the normal spectrum of events handled by the participating organizations (*emergencies*) and events that fall outside of this spectrum (*crisis*). This was the least complicated dimension, and generated little discussion.

Frequency of Exercises

The objective of the dimension *frequency of exercises* was to describe the recurring nature of an exercise. It was defined by four values: (1) *single exercise*, (2) *repeated exercises for one group*, (3) *repeated exercises for different groups* and (4) an *exercise series of increasing complexity*.

In the discussions, it was noted that many multi-agency inter-organizational exercises are indeed single exercises, that is, exercises that are neither repeated nor included in a series of exercises. This is also one of the major challenges. Firstly, the results from single exercises are subject to considerable uncertainties and has a low degree of validity. Secondly, there is often a tendency to try to include a large number of different objectives and elements in single exercises, with the risk of obscuring the main objectives. Single exercises can be used to test the system or to signal capacity.

The group identified three different variants of multiple exercises. The first one is an exercise that use the same exercise concept for a returning group of participants. This could be an exercise that regularly trains a specific ability, or collaboration or that is used to measure the development of a specific group's abilities. The second one is an exercise that use the same exercise concept for different groups. This could be an exercise that trains a number of groups in a specific ability, or collaboration, or that is used to measure the value of a specific method or specific procedures. Finally, the third type of multiple exercises is an exercise series with an increasing level of complexity. To be meaningful, it must generally be one and the same group that participate all through the exercise series. Such a series could be used to develop the overall ability of the system.

Resulting Morphological Field

The resulting morphological field is shown in Figure 2. It theoretically has 49 152 unique combinations of values.

Exercise Format	Exercise Objective	Exercise Planning Logic	Exercise Participants	Exercise Focus (Level)	Exercise Focus (Content)	Size and Character of Event	Frequency of Exercises	Types of Development Efforts
Table Top Exercise	Train/educate	Scenario driven	Novice/Beginner (professional)	Strategic	Skills	Emergency (event within the framework of the participating organisations' mandate)	Single exercise	Develop the exercise methodology
Functional Exercise	Test/evaluate	Capability driven	Competent (professional)	Tactical	Methods, Plans and Procedures	Crisis (event toutside the normal routines and processes of the participating organizations)	Repeated exercise (same exercise concept, same participants)	Increase the capability in the current crisis management system.
Full-scale (one actor, others are simulated)	Explore/develop		Skillful/Master (professional)	Operational	Concepts and Capabilities		Repeated exercise (same exercise concept, different participants)	Develop the crisis management system (within the current crisis management paradigm)
Full-scale (several actors)	Signal capability		Experts/academics	Multiple			Series of exercises, with gradually increased complexity	Transform the crisis management system (to something new, outside of today's paradigm.

Figure 2. The resulting morphological field.

Pairwise Comparisons

Overall, the field required that 424 individual comparisons were carried out. Some of these were relatively trivial. For instance, an exercise where most of the participants are *novices or beginners* co-exist poorly with the exercise objective of *signalling capability*.

Other comparisons were more complicated and the group had to revisit pairs several times to ensure consistency with other comparisons as their understanding of the morphological field increased. In some cases, the meaning of a dimension and its values was in the beginning blurred, and it took considerable time to reach a stable interpretation. One example of this was the field *Exercise Focus (content)*, where defining terms like *methods, plans and procedures* and *concepts and generic capabilities* required many iterations. The results of the pairwise comparisons are shown in Figure 3.

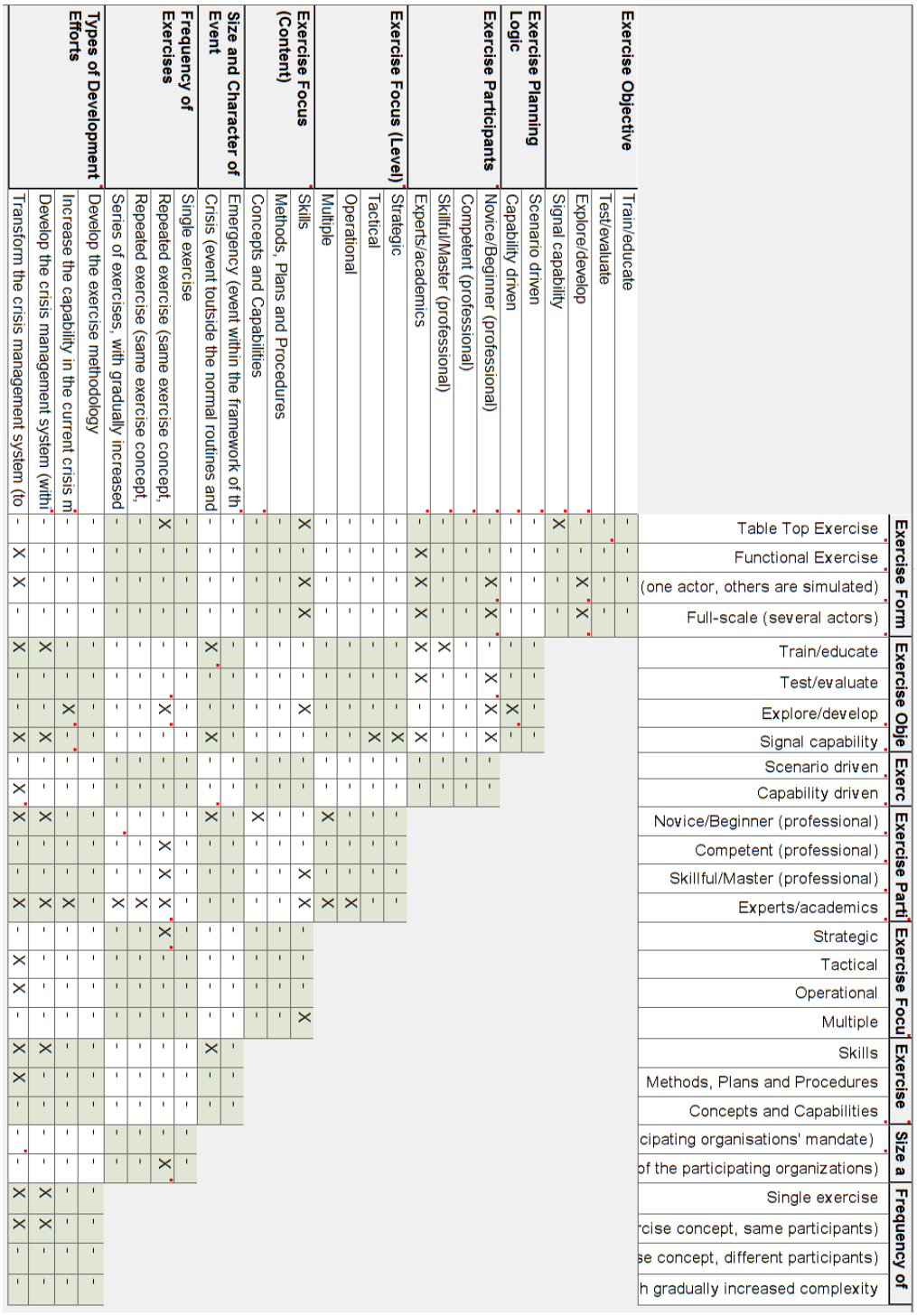


Figure 3. The results of the pairwise comparisons. X means that the values cannot co-exist.

Evaluation of the Field

The developed morphological field generated the expected results when focusing on the output dimension, i.e. the values in the dimension *types of development efforts (in which to use the results from the exercise)*. The value *develop the exercise methodology* was compatible with all the values in all the other dimensions, supporting the quite self-evident conclusion that whatever the type of exercise, it is possible to learn about how to design and implement exercises.

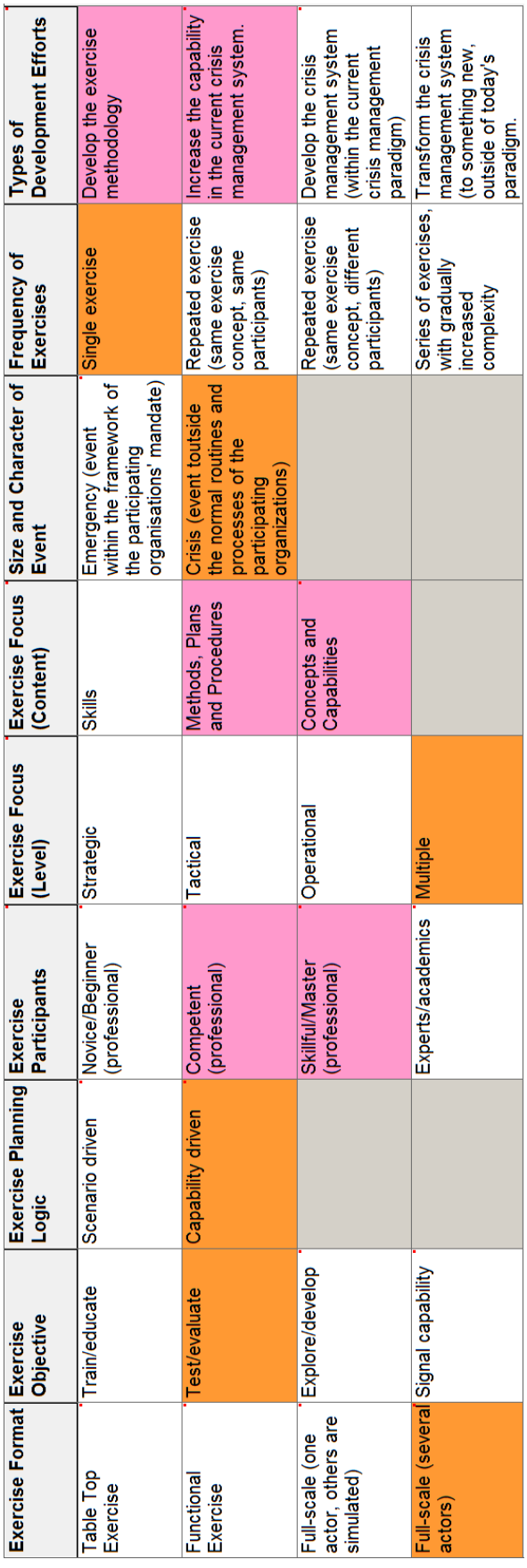
The next value in the output dimension, *increasing capability in the current crisis management system*, that is improving the quality of the system's components, is also compatible with most values of the other dimensions. This is no surprise, since most activities in any well-constructed exercise should have the potential to increase the capability of the current system in one way or another, for example training personnel and improving procedures. However, it is noticeable that this value is incompatible with explorative exercises. This may seem puzzling, but it is because of the inherent character of these exercises to explore beyond the current system paradigm. If a development need, for instance the need of extended training of personnel, is indicated by an explorative exercise, in most cases this needs be confirmed and validated through new exercises or through continued analysis to ensure its relevance also in the current system.

The third value, *develop the crisis management system within the limitations of the current paradigm*, that is developing different aspects in the system configuration without changing the configuration itself, is not compatible with exercises with the exercise objective to *train/educate*. Training/educating indicate that personnel are not fully skilled and thus any results regarding current system configuration's performance risk being flawed by the personnel's inadequate skill level. Similarly, this value is not compatible with exercises that focus on skills or participants that are novices/beginners. Furthermore, the model indicates that this type of development is only compatible with either several exercises using different groups or a series of exercises with successively increased complexity. A single exercise, or series of exercises with the same participants and without increasing complexity, will not yield the necessary knowledge to support the development of the system within the limitations of the current system. One exercise is not enough, and several exercises with the same participants will result in the participants learning to handle issues in the system, making these issues invisible and thus decreasing the value of the information that the exercise yields.

The final value in the output dimension, *transforming the crisis management system to something new outside the current paradigm*, that is changing the structure of the system's configuration, is incompatible with a number of different values in the other dimensions. For instance, it is incompatible with a capability driven exercise, mainly because a capability driven exercise presupposes the usage of a specific number of capabilities, leaving little room for exploring. Furthermore, the model indicates that this value is only compatible with an *exercise focus (level)* that involves the strategic decision-making level. This is because it is difficult to imagine that an exercise focusing on the tactical or operational would yield information implying that the whole paradigm must change.

When turning to specific combinations of exercise characteristics, to investigate compatible outputs, the field offers some interesting results. An exercise that has as its primary objective to *develop/explore*, cannot be combined with a planning logic that is *capability driven*, basically for the same reasons that capability driven exercises were incompatible with *transformation* in the dimension *types of development efforts*. Furthermore, if the value *explore*/*develop* is combined with *transformation*, the field indicates that this is only possible if a number of conditions are fulfilled. These are (1) that the exercise must be *scenario driven*, (2) that it should focus on the level *strategic decision-making* and (3) that it should focus on the content *concepts and capabilities*. Perhaps most noticeable, this combination of values is only compatible with the format *table-top*. This is a consequence of the fact that the exercise objective *explore/develop* cannot co-exist with any type of *full-scale exercise*, while the usage of results to *transform* the crisis management system excludes the format *functional exercises*. This does not, however, exclude that a functional exercise may have an *explore/develop* objective, for instance with the aim to generate results to develop the crisis management system.

A common combination of exercise characteristics, and perhaps the most expensive one, is the capability driven, full-scale exercise with the objective to test/evaluate the crisis management system and with a multiple-level focus. This type of exercise usually involves a crisis rather than an emergency and normally they are single events, although in some cases they may be part of a series of exercises (Figure 4).



Exercise Format	Exercise Objective	Exercise Planning Logic	Exercise Participants	Exercise Focus (Level)	Exercise Focus (Content)	Size and Character of Event	Frequency of Exercises	Types of Development Efforts
Table Top Exercise	Train/educate	Scenario driven	Novice/Beginner (professional)	Strategic	Skills	Emergency (event within the framework of the participating organisations' mandate)	Single exercise	Develop the exercise methodology
Functional Exercise	Test/evaluate	Capability driven	Competent (professional)	Tactical	Methods, Plans and Procedures	Crisis (event toutside the normal routines and processes of the participating organizations)	Repeated exercise (same exercise concept, same participants)	Increase the capability in the current crisis management system.
Full-scale (one actor, others are simulated)	Explore/develop		Skillful/Master (professional)	Operational	Concepts and Capabilities		Repeated exercise (same exercise concept, different participants)	Develop the crisis management system (within the current crisis management paradigm)
Full-scale (several actors)	Signal capability		Experts/academics	Multiple			Series of exercises, with gradually increased complexity	Transform the crisis management system (to something new, outside of today's paradigm.

Figur 4 The representation of a capability driven, full-scale exercise.

For this combination of values, the field indicates that the exercise's output is only useful for the development of exercise methodology and for the increase of capability in the current crisis management system. The reasons for

this are twofold. Single exercises cannot co-exist with neither the development within the current system, nor transformation of the crisis management system. Secondly, exercises with a capability driven planning logic cannot co-exist with transformation. In the Swedish context, the above characteristics are typical for the so-called SAMÖ-exercises, which are large scale, multi-agency inter-organizational exercises involving almost all sectors of the society. To use this type of expensive and complex exercise to try to find new ways of doing things is according to the model less productive unless the exercise is repeated or part of a series of exercises with gradually increased complexity.

DISCUSSION

Organizations within the crisis management domain invest extensive resources in exercises. Furthermore, multiagency inter-organizational exercises are expensive but also one of few opportunities, apart from real crisis, for sectors, organizations, and individuals to meet and interact with each other on crisis management issues. Although the ability of exercises to bring actors together in itself represent an important objective, other important objectives are to train, test, explore, and to produce knowledge for the development of the crisis management system.

Given the rarity of real crises, exercises are one of few sources of knowledge about crisis and crisis management. If the purpose is to provide knowledge for the development of the crisis management system, exercises need to be designed to fit this purpose.

The objective of this article was to explore if a morphological field can be used to investigate the relationship between the characteristics of a specific exercise and the usability of its results in different types of development efforts. The objective was not to determine the optimal morphological field for this cause. Still, we believe that most of the dimensions in the field presented in this article would be included by most groups, such as the dimensions format, participants and objectives. The validity of the field is also implied by the evaluation, generating both expected results for certain combinations of exercise characteristics and results that were somewhat more surprising but still could be explained from the underlying pairwise relationships in the field.

However, the morphological field presented in this article is not the only possible one to describe the relationship between the exercise design and the development of the crisis management system. Other groups may choose other dimensions or values. As an illustration of the non-absolute character of the morphological field, the group of experts at a late stage realized that an additional dimension could have been included: *type of evaluation*. Type of evaluation would affect what types of results that are yielded and how these results can be used. Examples of values for this dimension are *evaluation of goals*, *evaluation of processes* and *evaluation of effects*.

The next step in the research should be to involve a group of highly experienced practitioners to further validate the field, as well as to refine and expand it. The resulting field could be used as a tool for choosing and designing exercises that generate results with a high applicability for specific development efforts within the crisis management system.

CONCLUSIONS

This paper demonstrates that a morphological field can be used to investigate and understand the relationship between the exercise design and the usability of the exercise results in different types of development efforts. Even a quite simple morphological field offers results that deepen our understanding of this relationship. Further developed, we believe that a morphological field can be a powerful tool in designing exercises to fit the purpose of generating relevant knowledge for the development of the crisis management system.

ACKNOWLEDGEMENTS

This paper presents a study carried out within the research project KOMET, sponsored by the Swedish Civil Contingencies Agency (MSB).

REFERENCES

Argyris, C. and Schön, D. A. (1996) Organizational Learning II: Theory, Method and Practice, Addison-Wesley, Reading (MA).

Beerens, R. J. J. and Tehler, H. (2016) Scoping the Field of Disaster Exercise Evaluation – A Literature Overview and Analysis. *International Journal of Disaster Risk Reduction*, 19, 413-446.

Berlin, J. M. and Carlström, E. D. (2015) Collaboration Exercises: What Do They Contribute? – A Study of

Learning and Usefulness, *Journal of Contingencies and Crisis Management, 1*(23), 11-13.

Boin, A. (2009) The New World of Crisis and Crisis Management: Implications for Policymaking and Research, *Review of Policy Research*, 26, 4, 367-377.

Boin, A., Rhinard, M. and Ekengren, M. (2014) Managing Transboundary Crises: The Emergence of European Union Capacity, *Journal of Contingencies and Crisis Management*, 3, 22, 131-142.

Borodzicz, E. and van Haperen, K. (2002) Individual and Group Learning in Crisis Simulations, *Journal of Contingencies and Crisis Management*, 3, 10, 139-148.

Borrel, J. and Eriksson, K. (2013) Learning Effectiveness of Discussion-based Crisis Management Exercises, *International Journal of Disaster Risk Reduction*, 5, 28-37.

Comfort, L. K. (2007) Crisis Management in Hindsight: Cognition, Communication, Coordination, and Control. *Public Administration Review*, 67, 189-197.

Doyle, E. H., Paton, D. and Johnston, D. M. (2015) Enhancing Scientific Response in a Crisis: Evidence-based Approaches from Emergency Management in New Zealand, *Journal of Applied Volcanology*, 4, 1, 1-26.

Dreyfus, H. and Dreyfus, S. (1986) Why Computers may Never Think Like People, *Technology Review*, 89, 375-390.

Eriksson, P., Andersson, D., Hamann, K., Karapidis, A., Dworschak, B., van Rijk, R., van de Ven, J., Griffioen-Young, H., Stålheim, M., Szulejewski, M., Chagas, A., Rigaud, E., Rafalowski, C., Laist, I. and Joyanes, G. (2017) Lessons Learned Framework Concept, *DRIVER D530.1*, [https://www.driver-project.eu/wp-content/uploads/2017/11/Lessons-Learned-Framework-Concept.pdf]

Kim, H. (2014) Learning from UK Disaster Exercises: Policy Implications for Effective Emergency Preparedness, *Disasters*, 38, 4, 846-857.

Lagadec, P. (2009) A New Cosmology of Risks and Crises: Time for Radical Shift in Paradigm and Practice, *Review of Policy Research*, 26, 4, 473-486.

MSB (Swedish Civil Contingencies Agency) (2016) Exercise Guidance Basic Manual – An Introduction to the Fundamentals of Exercise Planning, Stockholm.

OECD (2015) The Changing Face of Strategic Crisis Management. OECD Reviews of Risk Management Policies, OECD Publishing, Paris.

Peters, G. B., (2017) What is so Wicked about Wicked Problems? A Conceptual Analysis and a Research Program, *Policy and Society*, 36, 3, 385-396.

Ritchey, T. (2006) Problem Structuring using Computer-aided Morphological Analysis, *Journal of the Operational Research Society*, 57, 792-801.

Ritchey, T. (2011) Wicked Problems – Social Messes: Decision Support Modelling with Morphological Analysis, Springer-Verlag, Berlin Heidelberg.

Sundelius, B., Stern, E. and Bynander, F. (1997) Krishantering på svenska – teori och praktik, Nerenius & Santérus, Stockholm.

Tillberg L. V. and Tillberg P. (2013) Mission Commander: Swedish Experiences of Command in the Expeditionary Era, Svenskt militärhistoriskt biblioteks förlag, Stockholm:

Wybo, J-L. (2004) Mastering Risk of Damage and Risks of Crisis: the Role of Organisational Learning, *International Journal of Emergency Management*, 2, 1-2, 22-34.

Do's and Don'ts in Inter-Organizational Crisis Management Exercises

Kristoffer Darin-Mattsson
Swedish Defence Research Agency
Kristoffer.mattsson@foi.se

Niklas Hallberg
Swedish Defence Research Agency
Niklas.hallberg@foi.se

ABSTRACT

It is commonly assumed that conducting exercises will contribute to better crisis management. However, the exact mechanisms of cause and effect are hard to isolate empirically. The objective of this paper is to compile and analyze the recommendations in the literature on inter-organizational exercises and learning. While not claiming to meet the strict scientific demand of empirical validation and general applicability, the compilation may nevertheless provide some guidance from research to practitioners. Forty-four papers about learning in inter-organizational exercises were analyzed. Out of the analyzed papers, 28 discussed obstacles or success factors. However, the recommendations applicable in one setting are not automatically valid in others, and some are even contradictory. The recommendations have therefore been categorized according to two criteria; when in the exercise cycle and for whom they apply. Several recommendations concern individual learning, but maximizing individual learning can sometimes hamper learning on the organizational level.

Keywords

Inter-organizational, exercise, learning, crisis management, collaboration

INTRODUCTION

Crises are major sudden events that affect many people. Regular resources and procedures are not enough for an unpredictable development, far- reaching consequences, and the need for a managed response from the society as a whole (Al-Dahash et al., 2016). This managed response requires collaboration between professionals in various organizations (Berlin and Carlström, 2014). Some of those organizations are used to inter-organizational collaboration and view it as a part of regular work, for instance the police and rescue services (Borodzicz and van Haperen 2002). However, in many crises, professionals and organizations that are not used to inter-organizational collaboration are needed in the response. Their main way of preparing themselves is through exercises.

It is commonly assumed that conducting crisis management exercises will contribute to better crisis management, but evidence suggests they often produce weak learning results (Borell and Eriksson, 2013). In addition, the exact cause and effect mechanisms are challenging to isolate and prove empirically (Wahl et al., 2015). Further, several researchers question the learning effect of exercises (e.g. Berlin and Carlström, 2015a; Beerens and Tehler, 2016;). As it is difficult to prove learning effects, let alone comparative effectiveness of various exercise designs, it is also difficult to decide on the best practice or guideline for crisis management exercises. One way to improve exercise practice is to compile recommendations in terms of what seems to work better or worse, even if no definitive answers can be provided.

There are a few compilations of do's and don'ts for exercises (e.g. van Laere et al., 2007, Berlin and Carlström, 2014; Grunnan and Fridheim, 2017). However, two of them are specific to format (role-playing exercise or simulation-games) (van Laere et al., 2007), and table-top (Grunnan and Fridheim, 2017), whereas one is limited to blue light services (Berlin and Carlström, 2014). None of them are specific for large scale inter-organizational exercises covering a whole of society response. However, there is reason to believe that the drawbacks as well as success factors identified in these studies can be valid for other kinds of exercises. Some of the exercises studied can be seen to be inter-organizational in nature.

The objective of this paper is to compile and analyze the recommendations in the research literature on the subject of inter-organizational exercises. The study is based on a scoping study covering learning in cross sectoral, inter-

organizational crisis management exercises.

BACKGROUND

Crisis management is aimed to prevent, protect against, respond to and recover from crises. These systems are inter-organizational by nature as crises are events that do not respect organizational boundaries. Furthermore, crises are not known beforehand and, therefore, the exact composition of a response organization cannot be narrowly defined in advance. Nor are crises frequent events, so the opportunity to learn, asses and evaluate the functioning of crisis management systems in real life are also rare. Therefore, exercises have a natural place within most crisis management systems (Bidinger et al., 2010). However, they can be used in different ways and for different purposes within a crisis management system.

One way of describing individual exercises and their role is to state the aim for conducting them, combined with a design description (e.g. table-top, full-scale, functional or simulation), and what kind of actors are part of it as well as a short scenario description. Aims for exercises are sometimes described as platforms for assessing capacities or validating plans and procedures (Bidinger et al., 2010). In addition, goals are often expressed in terms of capability building and/or learning (Berger et al., 2015). How learning or capability building actually takes place or how to measure it is less frequently discussed (Wahl et al., 2015; Berlin and Carlström, 2015b).

Inter-organizational exercises are different from many other types of crisis management exercises. In theory, they can use any format or kind of scenario and have many different objectives. They typically include several different organizations from different sectors of society and focus on collaboration in multi-agency responses fraught with conflicting objectives (Berlin and Carlström, 2014). They are often aimed at evaluating the crisis management response from a system perspective, rather than the individual's performance or the participating organizations. Therefore, there should be obstacles and success factors specific for this kind of exercises.

METHOD

According to Djikers (2016) the term scoping review has been used since 2001. It is used interchangeably with several other terms (e.g. scoping study, scoping report, evidence mapping, and systematic mapping). However, most researchers using the method use the one by Arksey and O´Malley (2005). This is also the case in the study presented in this paper.

The steps followed in this paper are the steps identified by Arksey and O´Malley (2005):

1. Identifying the research question
2. Identifying relevant studies
3. Study selection
4. Charting the data
5. Collating, summarizing and reporting the results

The research question in this study is: In terms of success factors and obstacles to successful learning, what recommendations does the literature offer concerning inter-organizational crisis management exercises? Relevant studies were identified through a search in the SCOPUS database using the search string: (learn*) AND (exercise*) AND (crisis OR emergency OR disaster). Only publications written in English were included. This generated a list of 744 papers. From the initial result relevant studies were selected in four steps; A title review, an abstract review, a quick full- length review and, finally, an in-depth full- length review.

In the title review, irrelevant papers were excluded. For instance, *emergency* might refer to individual psychological emergencies, the word *exercise* referred to workouts, or *crisis* was used to refer to a crisis of confidence. At this stage, 465 papers remained.

In the abstract review, three inclusion criteria were used. (i) The crisis/emergency/disaster described had to be of a magnitude that would require a large crisis management response from society, including several different organizations. (ii) The actual exercises presented must include several organizations from different sectors of society, or the exercise concepts presented must be relevant for organizations across different sectors of society. (iii) Some idea about how learning can be achieved through exercises must be stated, implicitly or explicitly. At this stage, 77 papers remained.

For the full- length review the same criteria as for the abstract review was used. After scanning through the papers, an additional 33 could be excluded on the grounds that they did not include any aspects of how learning can be achieved. Only statements indicating that something was indeed learned, typically in a topic or list. The remaining 44 papers formed the basis of the in- depth analysis

RESULTS

Forty-four articles about learning in inter-organizational exercises formed the basis for the analysis. Despite being about learning and inter-organizational crisis management exercises, not every paper discussed obstacles or success factors for learning. Out of the 44 analyzed papers, 28 discussed obstacles for learning and 26 success factors in some manner. In addition, in 13 papers the incentives for learning were mentioned. The success factors and obstacles identified in the literature were categorized and are presented in Table 1. However, the advice applicable in one circumstance is not automatically valid in other circumstances, and sometimes recommendations are contradictory. Therefore, the recommendations were categorized according to who (individuals, organizations or systems) is meant to learn, and when in the exercise cycle (planning, implementation, evaluation and dissemination) learning is meant to take place. There is no consensus about whose learning is the most important or if the learning is different in different phases, in terms of quality, quantity or effectiveness. Therefore, no grading of the recommendations are provided in the paper. However, it is clear that the focus of various papers is on different phases and entities of learning. By sorting them this way, seemingly contradictory recommendations can be reconciled.

Another effect of this tabular presentation is that it becomes clear that there is a lack of success factors identified in the literature when it comes to the dissemination phase as well as a systemic learning in general. This might be due to the scope of the study being too narrow. Perhaps these questions are dealt with more thoroughly under topics such as 'knowledge management and exercises', rather than learning and exercises.

Success factors

Four success factors were identified (Table 1).

Table 1. Success factors for learning in inter-organizational exercises

	Planning	Implementation	Evaluation	Dissemination
Individual level	Everyone learns	Variation Realism Everyone learns	Everyone learns	
Organizational level	Involve actors	Variation		
Systemic level	Involve actors			

Realism

Realism is the most frequently mentioned recommendation in the research literature (Meesters and Van de Walle, 2013). This primarily concerns the implementations phase of an exercise. According to Hills (2015), it is important that the scenario and format are realistic in order to expose the participants to a situation they find likely, so that they take it seriously and can experience the stress and pressure a real crisis would inflict on them. In this case, realism pertains to likelihood of the event as well as props. It is clearly aimed at learning opportunities for individuals by managing stressful situations. However, Borodzicz and van Haperen (2002) have claimed that too much focus on realism is bad as there is a risk that surprises and unlikely events are not taken into account on an organizational level and consequently not planned for, nor exercised. Crisis management is full of examples where the unforeseen and events deemed improbable have actually occurred.

Edzen (2014) has stressed that realistic means that there is no pre-established common understanding of what exactly the crisis consists of and how to respond properly. That is to say, the exercise must present a wicked problem. It is for the participants to define the crisis and find solutions through cooperation. Chen et al., (2008) claimed that exercises must be similar to the everyday workings of an organization in terms of the tools and support systems used. This is not always practiced; instead many exercises use alternative IT-support and computer aids not familiar to the participants. These kinds of exercises run the risk of teaching the participants the not in using tools, and not actual crisis management.

Variation

Variation is a recommendation thoroughly discussed in the literature. It also seems to be the most widely accepted one. The argument is that individuals need variation (in scenarios) in order to construct models of understanding

with general applicability (Borell and Eriksson, 2013). Variation can be understood as being important over a series of exercises such as slow or fast developments, different sectors, natural events or manmade ones (Chrichton et al., 2009). Another theme is variation within the same exercise, where "what if" scenarios can be developed (Macario et al., 2009). In both situations it is stressed that it is the possibility to compare and contrast different situations that enables the creation of general concepts and models. Borell and Eriksson (2013) adds that it is through dynamic scenarios, rich in variation, that facilitate unexpected meetings between individuals, combined with an openness for discoveries that constitute a good learning opportunity. Further, it could be argued that variation of format and design is important since they have the potential to generate qualitatively different results and conclusions.

Involve actors in the planning

This factor is about ownership of the results and willingness to learn from an exercise. Adult learning is sometimes different from traditional pedagogy, which is aimed at children. Adult learning (andragogy) demands a higher involvement of the learner in the planning processes with respect to what and how to learn (Tretsiakova-Mcnally, 2017). In a more practical sense, it is a fact that in inter-organisational exercises, no single organization controls all relevant factors. For instance, participating organisations often control what representative they send to an exercise. In order to select the right people, and the right format and content for the aims and purposes of an exercise, a great deal of coordination is needed in the planning process. It is also the case that a central organization does not always know what participating organizations need to exercise, nor what they want to exercise. This needs to be settled in the early planning stages and is best done through collaboration (Gleason, 2003). Many inter-organizational exercises focus on collaboration. To make sure that collaboration is actually needed during an exercise, the scenario and design need to be chosen with this is mind (Andersson, 2016). Constructing them together is a simple solution to this problem.

Everyone learns

When it comes to theories of learning, focus is often on the exercised individual. The rationale is that participation in exercises teaches the participant something. Through evaluation process, organizations and systems too are offered an opportunity to improve themselves by internalizing the results described in the evaluation report. However, this is too narrow a focus. Planners, observers, facilitators and evaluators could also learn from their involvement in the exercise. Borodzicz and Van Haperen (2002) suggested that participation in these functions constitutes a learning opportunity equally important as participation in the exercise, albeit a much less studied learning opportunity. Considering who is asked to plan, facilitate and evaluate exercises as well as consider who participates thus becomes important. Further, the evaluation should also take into account the experiences of others than the participants. This is rarely done in a structured way, for instance, hot washes are not meant for facilitators and observers (Borodzicz and Van Haperen, 2002).

Obstacles

Nine obstacles for learning were identified in the literature and are presented in Table 2.

Table 2. Obstacles for learning in inter-organizational exercises

	Planning	Implementation	Evaluation	Dissemination
Individual level	Manage expectations Complexity	Wrong participants Manage participants Wrong focus	Manage resources	
Organizational level	Manage resources Complexity	Wrong focus Lack of learning culture	Wrong participants Unfocused	Comparable documentation Lessons not shared
Systemic level	Manage expectations	Wrong participants Wrong focus Lack of learning culture	Manage expectations Wrong participants Unfocused	No incitement Comparable documentation

The wrong thing is exercised

In the field of crisis management, work is being done to analyze risks and vulnerabilities, to identify what preparations should be made and what needs to be exercised. Unfortunately, these are not always the things that are subsequently exercised. Often, exercises focus on decision- making processes and information management, and the exercise typically starts well into an ongoing scenario. At the same time, research has pointed out that the early phase before an event has been defined as a crisis situation that needs to be exercised (van Laere et al., 2007).

It should be noted that few of the exercises analyzed in this study concern typical inter-organizational aims and tasks. In fact, some of them could be described as organizational exercises running in parallel. Anderson et al. (2016) suggested that the focus for inter-organizational exercises should be the boundaries between exercising organisations. The purpose of inter-organizational as opposed to intra-organisational is to learn the specifics of coordination and collaborative work, rather than the regular procedures of one's own organization. Examples given are differences in vocabulary, priorities and overlapping responsibilities.

The wrong people are exercised

Who participates in an exercise is important, and failure to include the right people is pointed out as a frequent problem in the literature. The choice of who is to participate must be made early in the process, keeping in mind what level participants should be at and preparing them for the exercise at an early stage (Grunnan and Fridheim, 2017). Choosing the wrong participants can happen in several different ways. A great deal of crisis management is carried out by private actors who frequently do not participate in exercises conducted by government agencies. The public is also an important actor in crisis management. However, few exercises are aimed at the general public. A different mistake in choosing participants is that missing parties affect the realism of the exercise and cause great strain on facilitators who then have to simulate their participation. Therefore, it is often difficult to determine if the simulation was good enough (van Laere et al., 2007). Another problem is that participants sometimes are under-prepared and that more senior participants were needed. A frequent mistake in these circumstances is blaming the failure on plans and procedures instead of lack of preparation and selecting the right participants. An additional problem is that no one from the participating organizations has the mandate (in their own organization) to act on any identified measures for improvement (Macario et al., 2009).

Manage resources, participant and expectations

Different actors sometimes have different expectations and understandings of the purpose and goal of an exercise (Meesters and Van de Walle, 2013, Rutty and Rutty, 2012). This has consequences for who will participate in an exercise. For instance, one actor sends new member of staff to participate because the exercise is seen as an opportunity for them to learn. However, other actors understand the purpose to be a test of the system and therefore send their most experienced people. This mismatch is likely to cause friction and make evaluation more difficult. It is often the case that several purposes are adopted for an exercise without considering the consequences regarding participants and the exercise design.

Exercises are often designed with a focus on the intended participants. Participants in exercises often contribute to the design of the exercise both at the planning stage, as they often influence the scenario, and during the exercise when their estimates of time and effect of different actions are allowed to drive the exercise forward. Participants may refer to resources that are not actually available and overestimate the effects of their chosen actions while underestimating the timeframe (van Laere et al., 2007). The focus on the participants also has consequences for the evaluation work, hot-wash being a common example. In these, evaluators try to capture the participants' experiences (what they learned). It is equally important that observers and evaluators themselves participate and give their views, which often complement or even contradict the participants' experiences. Their view is important, both for feedback and for a broader context for the participants (Borodzicz and van Haperen, 2002).

Participants' efforts in hot-washes and other evaluation efforts are often inadequate. Gleason (2003) suggested that this may be because they are tired and want to go home. In many cases they have struggled through an intensive management simulation and were never given an opportunity to learn or reflect on alternatives. The latter can also be said about exercise managers. They focused on implementation and did not plan for the whole process. After the implementation, resources are drained and when the time comes for evaluation and experience management, there are no resources left (van Laere et al., 2007). For a successful exercise, planning must cover the whole process.

Choose complexity level carefully

Too many exercises are conducted in a vacuum in relation to other exercises. They are often planed and conducted as well as evaluated as a one of event and managed and financed as a project rather than as part of a continuous series of exercises. It is normally better to plan the complexity of an exercise progressively, where one exercise

build on a previous one (Kim, 2014). This makes it easier to view learning as a cumulative and ongoing process, leading to a focus beyond testing existing procedures and producing an accurate description of the current status.

Complex scenarios also make it difficult to exercise in inter-organizational settings, since there is a risk that a situation will be created where one organization has to wait for another for long periods during the exercise. Moreover, too much complexity can result in everyone waiting for someone else to take the lead (Berlin and Carlström, 2014).

The lack of a gradually increasing difficulty level makes it harder to match participants with a suitable level of difficulty. The complexity and difficulty level of an exercise is very important. If participants enter into an exercise that is too difficult their learning is compromised. On the other hand, if participants are too qualified there is nothing to learn (Rankin et al., 2012). They also risk jeopardizing the learning for the participants for whom the exercise is suitable. A common mistake in this respect is to simplify what should be a very complex exercise. It is better to choose a simpler scenario and format altogether, rather than simplifying a difficult one (Borodzicz and van Haperen, 2002). Another way of handling complexity levels far above the participants' capability is through active instructor participation (Rankin et al., 2012).

Unfocused Evaluation

An evaluation cannot capture everything. It has to be selective and focused on specific aims; otherwise it runs the risk of being superficial. Furthermore, there is often too high expectations on the observers' capability to see and hear and understand everything that is going on (Greenberg et al., 2017). Also evaluation is not just the report, it is the planning for and the actual organization for constructing, collecting and analyzing data during and after the exercise. This is often an organization with a limited budget and timeframe.

The exercise format and scenario do not match the goals of the evaluation. First, the format and scenario are chosen and only thereafter, ad hoc, the evaluation aims. The objectives must control the choice of format and scenario. Otherwise, there is a risk that the same mistakes reappear in later exercises (van Laere et al., 2007).

Lessons are not shared

A common mistake is that conclusions and recommendations are not allowed to spread outside the circle of those directly concerned. Chricton et al. (2009) believe that the threshold for learning from other actors and sectors of society may be high due to differences of contexts and terminology, differences that lead to greater resource utilization to adapt conclusions and recommendations. Furthermore, this may also be the case because the relevance is deemed to be low when conclusions are drawn by others outside one's own organization. One solution is to position exercises as part of a larger process of change. (Chricton et al., 2009) Lessons learned by other organizations and in exercises where the scope is broader than in one's own sector are often relevant. This is obvious as the same conclusions are often drawn in different exercises in different fields and, moreover, repeatedly over time for the same actors. This sometimes leads to frustration and scepticism towards exercises as a driver of change (Savoia et al., 2012). Epler and Hunt (1999) emphasized that the problem with exercises are that they often show the same result. Yet, participants often learn anyway, although the lessons are not translated into changed procedures or internalized on an organizational level. This risk is likely to be higher in inter-organizational exercises as no single organization can be said to fully own the results and responsibility for improvement.

Lack of learning culture

Some actors will try to distort results in evaluations or not share correct information during exercises. According to Upton (2009), both individuals and organizations, particularly in inter-organizational settings, feel that their reputation is at risk as the results may be seen as a comment on their plans and preparations. Further, a poor result may be used against them in the future by pressure groups or public opinion. Therefore, an unofficial goal of not looking bad tends to be a part of exercises. In addition, people can be afraid or uncertain and hide information or choose not to act in fear of mistakes (Hills, 2015). In organizations there is often a natural resistance to change. It is costly and admitting faults or failure can change power balances within organizations (Upton, 2009). It is difficult but important to foster a culture of learning in exercises (Kim, 2013).

Lack of comparable documentation

Lack of comparable documentation is about the fact that reporting about exercises is not very stringent. It mainly concerns the lack of a common reporting format and archiving of evaluation reports, for instance after action reports (AAR) (Savoia et al., 2012). Systems and archives for the documentation of exercises must be available in order to avoid making the same mistakes over and over, as well as create aggregated conclusions. However,

there is also a lack of common terminology for exercises between organizations, societal sectors and in research, which makes it difficult to use and learn from archive material (Upton, 2009).

Lack of clear incentives to learn

A possible obstacle not explicitly mentioned in the analyzed material, is the creation of clearer incentives for learning. By and large there seems to be a lack of incentives (Gleason, 2003). Upton (2009) pointed out that for market actors there are financial incentives, but for the crisis community the only incentive for individuals is personal enjoyment in participating in exercises and the idea of learning something new. This, however, is not the same thing as formal incentives. This lack of incentives to learn and, even more so, to change practices permanently might be a reason why many exercises seem to generate the same results over time (Meesters and van de Walle, 2013). Others have pointed out that gaining a better and more flexible organization is an incentive in itself (e.g. Hills, 2015; Chricton et al., 2013). Rutty and Rutty (2012) explored the reasons why participants want to learn, but also pointed out that their reasons do not have to align with planners' and organizations' reasons. On an organizational level there is a lack of incentive to change.

DISCUSSION

A few of the recommended success factors are contradictory, although some contradictions can be easily solved. They apply to different circumstances and can be valid both in their own situation and in relation to a specific purpose. However, the need for realism in order to increase individual learning while simultaneously running the risk of not exposing organizations for improbable, yet possible, scenarios is hard to reconcile within the framework of a single exercise. This must be a strategic choice in the planning process.

Many authors in the analyzed papers have an idea of who is meant to learn and when learning takes place. However, few have grounded this in a theory of learning. This idea most often consists of an activity within the framework of exercises that the author highlights as the most important learning opportunity. For instance, several authors (e.g. Epler and Hunt, 1999; Savoia et al., 2012; Upton, 2009) have pointed to the evaluation as the most important learning opportunity. This position tends to correlate with a focus on organizational learning, where findings in the evaluation report can lead to updates and changes in guidelines, divisions of responsibilities or mandate. Others focus more on individual learning (e.g. Berger et al., 2015; Chen, 2014), and therefore tend to highlight participation in an exercise as the prime learning opportunity. In addition to this, debriefing discussions after exercises are often highlighted as the main learning opportunity for the individuals (e.g. Biddinger et al., 2010; Gleason, 2003; Greenberg et al., 2017). Less common but still argued by a few is the view that the planning and observation of exercises constitute the best learning opportunities (Borodzics and Haperen, 2002). This view is based on the assumption that planning and observing an exercise provides a position where a more holistic understanding can be gained compared to participation, and that that is more important than enhancing individual skills.

Differences of opinion when it comes to what constitutes the best opportunities for learning can to a large extent be explained by different views on who should learn; is it the individual, the team, organizations or inter-organizational systems of crisis management? Another factor for explaining this is that there is a great variation in the views of what it is that is important to learn, for instance, personal knowledge (such as how to handle your own stress and how others respond to stress), or skills (everything from how to use IT support programs, operate heavy machinery or treat wounds), or capabilities (such as communication with the public, decision-making processes and prioritization). These capabilities are often conceptualized as the right configuration of a set of skills appropriate for the situation at hand. A select few of the papers analyzed also stressed that the most important thing to learn is a holistic understanding of crisis management rather than individual feelings and reactions, skills and capabilities.

Learning in inter-organizational exercises was the focus in the analyzed papers. It is, therefore, surprising that a large part of the material dealt primarily with individual learning and skills. There are individual skills that can only be learned in inter-organizational settings, e.g. collaboration between individuals from blue light organizations with different responsibilities on an emergency site (Berlin and Calström 2014). However, much of the skills and capabilities described in the literature is not inter-organizational in nature. For instance, learning the procedures and guidelines of one's organization can be done in an intra-organizational setting, which is often less costly. To adapt to conflicts of interest between different organizations' goals and procedures should be the focus of inter-organizational settings (Andersson, 2016). This suggests that the practicing of intra-organizational procedures should not be exercised together with others, only the specific aim of testing how they work in relation to other organizations' procedures. Hence, procedures in one's own organization should be well practiced before entering into inter-organizational exercises. This further highlights the need for the right participants.

The fact that no clear incentive for learning seems to exist is surprising and a likely cause for why few findings during exercises seem to be implemented. Further, little advice concerning dissemination of results from exercises is provided. This might be an effect of the focus on exercises in this paper rather than knowledge management or policy formulation. Nevertheless, it is interesting considering the fact that exercises are often expensive and that the aim of spreading lessons from an exercise in wider circles than the directly affected often is a part of crisis management exercises.

CONCLUSION

The main contribution of this paper is four factors that favor learning from exercises and nine obstacles that hampers learning from exercises. These factors can contribute to the planning and execution of inter-organizational exercises. Hence, making use of these factors may contribute to more successful inter-organizational exercises.

ACKNOWLEDGEMENT

This paper presents a study carried out within the research project KOMET, sponsored by the Swedish Civil Contingency Agency.

REFERENCES

Al-Dahash, H., Thayaparan, M. and Kulatunga, U. (2016) Understanding the Terminologies: Disaster, Crisis and Emergency, *Management*, *2*, 1191-1200.

Andersson, A. (2016) Boundaries as Mechanisms for Learning in Emergency Exercises with Students from Emergency Service Organisations, *Journal of Vocational Education & Training*, *68*, 2, 245-262.

Andersson, A., Carlström, E. D., Ahgren, B. and Berlin, J. M. (2014) Managing Boundaries at the Accident Scene - A Qualitative Study of Collaboration Exercises. *International Journal of Emergency Services*, 3, 1, 77-94.

Arksey, H. and O'Malley, L. (2005). Scoping Studies: Towards a Methodological Framework, *International Journal of Social Research Methodology: Theory and Practice*, 8, 1, 19-32.

Beerens, R. J. J. and Tehler, H. (2016) Scoping the field of Disaster Exercise Evaluation - A Literature Overview and Analysis, *International Journal of Disaster Risk Reduction*, *19*, 413–446.

Berger, T., Fogel, I., Poles, L., Aran, A. A., Shental, O. and Kassirer, M. (2015) Implications Drawn from a Military Bioterror Exercise in Israel, *Health Security*, 13, 2.

Berlin, J. M. and Carlström, E. D. (2015a) The Three-Level Collaboration Exercise - Impact of Learning and Usefulness, *Journal of Contingencies and Crisis Management*, 23, 4, 257-265.

Berlin, J. M. and Carlström, E. D. (2014) Collaboration Exercises-The Lack of Collaborative Benefits, *International Journal of Disaster Risk Science*, 5, 3, 192-205.

Berlin, J. M. and Carlström, E. D. (2015b) Collaboration Exercises: What do they Contribute? - A Study of Learning and Usefulness, *Journal of Contingencies and Crisis Management*, 23, 1, 11-23.

Biddinger, P. D., Savoia, E., Massin-Short, S. B., Preston, J. and Stoto, M. A. (2010) Public Health Emergency Preparedness Exercises: Lessons Learned, *Public Health Reports*, 125, 5, 2010

Borell, J. and Eriksson, K. (2013) Learning Effectiveness of Discussion-based Crisis Management Exercises, *International Journal of Disaster Risk Reduction*, 5, 28-37.

Borodzicz, E. and Van Haperen, K. (2002) Individual and Group Learning in Crisis Simulations, *Journal of contingencies and crisis management,* 10, 3, 139-147.

Chen, Y. F. (2014) Evaluation of Strategic Emergency Response Training on an OLIVE Platform, *Simulation and Gaming*, 45, 6, 732-751.

Chen, Y.-F., Rebolledo-Mendez, G., Liarokapis, F., De Freitas, S. and Parker, E. (2008) The Use of Virtual World Platforms for Supporting an Emergency Response Training Exercise.

Chrichton, M. T., Ramsay, C. G. and Kelly, T. (2009) Enhancing Organizational Resilience Through Emergency Planning: Learnings from Cross-Sectoral Lessons, *Journal of Contingencies and Crisis management*, 17, 1, 24-37.

Dijkers, M. (2015) What is a Scoping Review? *KT Update* e-newsletter from the Center on Knowledge Translation for Disability and Rehabilitation Research, 4, 1.

Edzen, S. (2014) Table-top Exercises for Emergency Management: Tame Solutions for Wicked Problems, *In Proceedings of the Annual Hawaii International Conference on System Sciences*.

Epler, G. F. and Hunt, W. (1999) The Pipeline Industry-Planning and Exercising: Is Industry Deriving Full Benefit from Lessons Learned? *Proceedings of the International Oil Spill Conference.*

Greenberg, B., Voevodsky, P., and Gralla, E. (2017) A Capabilities-Based Framework for Disaster Response Exercise Design and Evaluation: Findings from Oil Spill Response Exercises. *Journal of Homeland Security and Emergency Management*, 13, 4.

Grunnan, T. and Fridheim, H. (2017) Planning and Conducting Crisis Management Exercises for Decision-Making: the Do's and Don'ts. *EURO Journal on Decision Processes*, 5, 1-4, 79-95.

Hills, M. (2015) Assuring Organisational Resilience with Lean Scenario-driven Exercises. *International Journal of Emergency Services*, 4, 1, 37-49.

Gleason, L. (2003) Taking a Step Back. Exercises as Training Opportunities. *International Oil Spill Conference Proceedings,* 2003, 1, 1055-1058.

Kim, H. (2014) Learning from UK disaster exercises: Policy implications for effective emergency preparedness, *Disasters,* 38, 4, 846-857.

Kim, H. (2013) Improving simulation exercises in Korea for disaster preparedness, *Disaster Prevention and Management: An International Journal*, 22, 1, 38-47.

van Laere, J. van, Lindblom, J. and Susi, T. (2007) Requirements for emergency management training from a'passion for failures' perspective, *Proceedings ISCRAM2007,* 449-456

Macario, E., Heyden, L., and Nakahara, N., (2009) Preparing for a Pandemic Influenza: California Confronts the Legal Implications, *Health Promotion Practice,* 2009, 10, 4.

Meesters, K. and Van De Walle, B. (2013) Disaster in my backyard: a serious game introduction to disaster information management, *Proceedings of the 10th International ISCRAM Conference,* 145-150.

Rankin, A., Field, J., Kovordanyi, R., and Eriksson, H. (2012) Instructor's Tasks in Crisis Management Training, *Proceedings of the 9th International ISCRAM Conference,* 1-5.

Rutty, G. N. and Rutty, J. E. (2012) Did the participants of the mass fatality exercise Operation Torch learn anything? *Forensic Science, Medicine, and Pathology*, 8, 2, 88-93.

Savoia, E., Agboola, F. and Biddinger, P. D. (2012) Use of after action reports (AARs) to promote organizational and systems learning in emergency preparedness. *International Journal of Environmental Research and Public Health*. 9, 8, 2949-2963.

Tretsiakova-McNally, S., Maranne, E., Verbecke, F., & Molkov, V. (2017). Mixed e-learning and Virtual Reality Pedagogical Approach for Innovative Hydrogen Safety Training of First Responders, *International Journal of Hydrogen Energy*, 42, 11, 7504-7512.

Upton, D. (2009) some suggestions for making emergency response exercises more consistent and more successful, *In: Strategizing Resilience and Reducing Vulnerability*

Wahl, E., Willumsen, B., Jensvoll, L., Finstad, I. H. and Berglund, T. M. (2015) The learning effect of a foodborne emergency exercise. *British Food Journal*, 117, 7, 1981-1994.

Testing the implementation of a flying localization system into emergency response using a tabletop exercise

Sebastian Schmitz
TH Köln – University of Applied Sciences
sebastian.schmitz1@th-koeln.de

Konrad Barth
TH Köln – University of Applied Sciences
konrad.barth@th-koeln.de

Tim Brüstle
TH Köln – University of Applied Sciences
tim_niklas.bruestle@smail.th-koeln.de

Tobias Gleibs
TH Köln – University of Applied Sciences
tobias_emanuel.gleibs@th-koeln.de

Ompe Aimé Mudimu
TH Köln – University of Applied Sciences
ompe_aime.mudimu@th-koeln.de

ABSTRACT

To optimize the search for trapped victims after building collapses, the authors participated in the development of a localization system based on an unmanned aerial vehicle. The objective of this study is to evaluate an approach to implement this system into the command and control structures during the emergency response after a building collapse. For this purpose, a tabletop exercise, based on a gas explosion scenario in an apartment building, was carried out with emergency response managers of the fire department and the German federal agency of technical relief. Observers have documented the exercise. Additionally, audio and video recordings were used. Thus, statements could be made about the implementation approach and the tabletop exercise method. Based on the results, the implementation approach can be considered appropriate. In addition, knowledge was gained about the appropriateness of tabletop exercises for the purpose of scientific evaluation.

Keywords

Urban search and rescue, unmanned aerial vehicle, command and control structures, tabletop exercise, emergency management

INTRODUCTION

The successful search for trapped victims during urban search and rescue (USAR) operations is affected by different factors. Besides the successful localization of trapped victims, the safety of rescuers is of particular importance (Statheropoulos et al. 2015). The research project "Flying localization system for the rescue and recovery of trapped victims" (German acronym: FOUNT^2) takes up these issues and aims at optimizing the localization of trapped victims as well as at enhancing the safety of rescuers after a building collapse.

To enable a more efficient search for trapped victims after a building collapse, a semi-autonomous, unmanned aerial vehicle (UAV) equipped with automatic landing site detection as well as bioradar is being developed within FOUNT^2. Information about signs of life and the position of trapped victims are generated by the bioradar. The mission planning and the analysis of the bioradar data is carried out via a user interface. By integrating the bioradar into the UAV, trapped victims can be located without rescuers setting foot on the debris structures, thereby reducing the risk of rescuers becoming injured or buried by further building collapses. Furthermore, the UAV can provide a bird's eye overview of the collapse site to support mission planning.

The task of the Institute of Rescue Engineering and Civil Protection (German acronym: IRG) within the project

is, among other things, the development and evaluation of an approach for the implementation of the FOUNT² system in the command and control structures during USAR operations. Based on a gas explosion scenario that takes past incidents into account, several implementation approaches have been described by researchers of the IRG and evaluated by four emergency managers in expert interviews. All interviewed experts are full-time or voluntary emergency managers at German fire departments or in the field of civil protection. In addition, all of them are active in higher education for future emergency response managers at TH Köln. In Germany, primarily the fire departments are responsible for emergency response after building collapses. Therefore, all implementation approaches are based on the fire service regulation 100 "leadership and command in emergency operations" (German acronym: FwDV 100) as well as the guideline 03/01 "instructions for actions of the fire service and other emergency responders after building collapses" of the German Fire Protection Association (GFPA, German acronym: vfdb) (AFKzV 1999; vfdb 2005).

Figure 1 shows the final approach for implementing the FOUNT² system into the command and control structures that was considered appropriate by the interviewed experts. According to this, the FOUNT² system is assigned as a device for technical search to the search subsector, which is part of the search and rescue sector. In this subsector, the sole control of the system is located, which enables control/command input ("full access", marked in dark blue in Figure 1). Control/command input is carried out by the so-called "FOUNT² operator" using a tablet computer, which runs the FOUNT² user interface. In order to optimize the flow of information, further access options are provided to the command staff, the search and rescue sector commander, the scene protection and safety sector (hereinafter referred to as "safety sector") commander as well as the search subsector commander and the rescue subsector commander. Using these options, information access is available by other devices, but no control of the system is possible ("read-only access", marked in light blue in Figure 1).

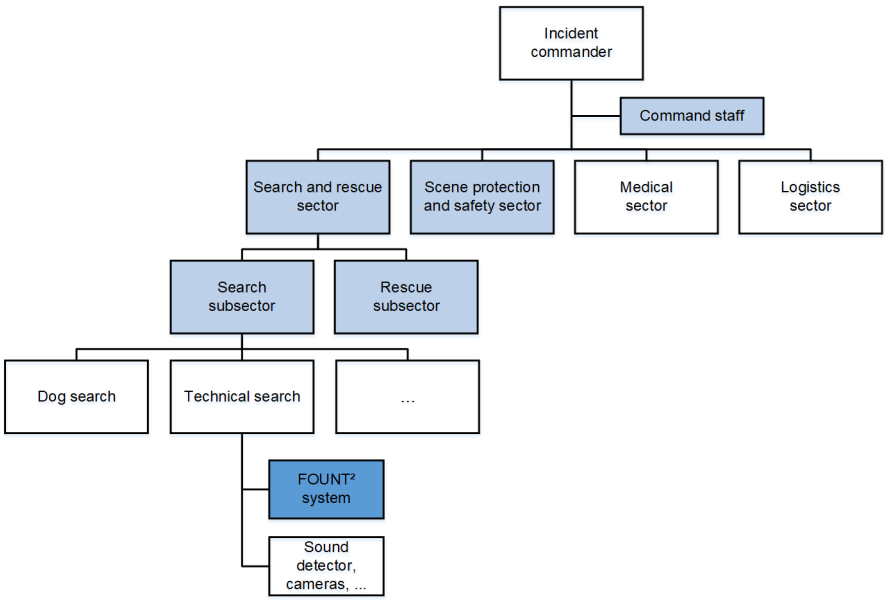


Figure 1. Approach to Implement the FOUNT² System into Command and Control Structures
(Own figure based on vfdb 2005)

To evaluate the implementation approach, the authors conducted a tabletop exercise with emergency management experts. Tabletop exercises are used in the field of emergency response for education and training of emergency response managers (Alexander 2002). These exercises provide the opportunity to bring various experts in the field of emergency response together to test coordination and response in a safe environment as well as to identify weaknesses of plans and procedures (Alexander 2002; Smith et al. 1999, qtd. in van Niekerk et al. 2015). In Germany, the command process defined in the FwDV 100 is used in emergency response missions and as basis for tabletop exercises in this field. The focus of tabletop exercises is the decision making of emergency managers. The medium used for the simulation usually is a diorama (shown in Figure 2), on which the incident situation is depicted in an abstract form using building and vehicle models. (Rempe et al. 2015) During the exercise, the participants verbalize relevant aspects of their decision making so that other participants can understand their actions. Additionally, the participants can enter into a dialogue with the exercise instructor.

Within the tabletop exercise conducted in this study, the following research questions were to be answered:

1. Which weaknesses/errors of the implementation approach can be identified?
2. Do the positions within the command and control structures that are addressed directly or indirectly by the FOUNT² system receive the information provided by FOUNT²? Is this information used and forwarded if necessary?

METHODS

The evaluation process was divided in three phases: preparation, conduct of the tabletop exercise as well as debriefing and data analysis.

Preparation

During the preparation phase, an exercises concept, a scenario description and an exercise script were developed. The exercise concept contained information about the objectives, the involved parties and the observation methods. The exercise script was based on the manual for strategic crisis management exercises of the Federal Office of Civil Protection and Disaster Assistance and contained the planned chronological order of the exercise as well as the information to be released during the exercise (BBK 2011). The detailed design of the exercise script also ensured the reproducibility of the tabletop exercise.

In preparation for the exercise, all participants received a presentation of the implementation approach and the emergency response units available in the exercise. Furthermore, information about the functions of the FOUNT^2 system as well as the tasks and procedures of their position according to the GFPA guideline 03/01 was provided to the participants. Additionally, a short presentation of those aspects took place at the day of the exercise.

Adjustments

The implementation approach shown in Figure 1 depicts the command and control structures in a real-life mission. However, the conditions of the exercise required some adjustments in order to realize this approach. The division of the search and rescue sector into two subsectors in the exercise would have been unreasonable and not necessary. Due to the physical proximity of the sector commander to the subsector commanders in the laboratory, everyone receives new information at the same time, although in reality this information must first be communicated from one person to another. For this reason, the subsector search and the subsector rescue are not displayed and the FOUNT^2 read-only access of the rescue subsector commander is transferred to the search and rescue sector commander. The documentation of the command and control structures was given to the participants, so that no alternative structures were used. This is comparable to the definition of a binding tactical standard procedure.

At the time of the exercise, the user interface of the FOUNT^2 system was not yet available in a functional scope that allowed complete interaction. Therefore, the information provided by the system (e.g. measurement diagrams of the bioradar) was released using printouts. Furthermore, a distraction of the participants by the operation of an unknown technical device during the simulation was to be avoided.

Scenario

To obtain a scenario that is both realistic and suitable for the evaluation, the requirements of the various actors in a rescue mission for trapped victims as well as the conditions necessary for the deployment of the FOUNT^2 system were considered during scenario development. An analysis of past real-life missions with trapped victims was carried out based on these criteria. The resulting exemplary scenario was a collapse of an apartment building in a residential area caused by a gas explosion. The scenario used in the tabletop exercise was based on a gas explosion that took place on March 31, 2017 in Dortmund (Germany). Table 1 lists the scenarios' boundary conditions derived from that incident.

To cope with the scenario, the participants had the tactical units listed in the GFPA guideline 03/01 at their disposal. The authors specified the compilation of tactical units, based on the generic terms in the guideline, with regard to the number and type of vehicles and personnel. Table 2 lists the units available in the exercise and their simulated time of arrival. Only emergency response managers who are represented in the exercise are listed. All other managers (e.g. subsector commander) are counted as operational personnel. The times of arrival are based on planning specifications from reality or on the experience of the authors. They were defined in such a way that the command and control structure envisaged in the implementation approach can be formed immediately and no alternative structure is established. For this reason, the incident commander and the search and rescue sector commander as well as the safety sector commander arrived at the same time.

Table 1. Boundary Conditions of the Gas Explosion Scenario

	Description
Localization of the incident	Residential area south of the city center in a town with about 600,000 residents.
Incident cause	Gas explosion intentionally caused by manipulation of the gas pipe
Development	Side street with multi-story terraced apartment buildings on both sides, sidewalks in front of the buildings
Description of the affected building	Partly collapsed, three-story residential building with several residential units Design: masonry with wooden ceilings Front: sidewalk Back: common courtyard with garden and a small playground
Access to the affected building	Front: access via side street, entrance through the front door Back: passage through the house into the courtyard, vehicle access via a passageway between the neighboring houses
Time, Weather	Thursday, May 3, 2018, sunny, clear sky, 22°C / 11°C
Number of trapped victims	5
Number of injured victims	5
Number of uninjured affected	15
Deployable localization means	Physical surface search (hailing) Rescue dogs Endoscopic camera Cell phone localization Bioradar / FOUNT[2] system
Deployable safety means	Site stability monitoring system Shoring system to stabilize adjacent buildings
Types of collapse involved	Lean-to collapse, pancake collapse, cantilever collapse

Table 2. Deployable Tactical Units
(Own figure based on vfdb 2005)

Vehicles	Personnel	Time of arrival
Fire and medical services		
1x command vehicle type 1	1x incident commander, 1x assistant	After 8 minutes
1x command vehicle type 2	1x logistics sector commander, 1x command staff	After 15 minutes
2x fire company[1]	1x search and rescue sector commander, 1x safety sector commander, 20x firefighter	After 8 minutes
1x rescue truck	2x firefighter	After 30 minutes
1x crane	2x firefighter	After 30 minutes
1x FOUNT[2] truck	1x FOUNT[2] operator	After 30 minutes
1x command vehicle	1x medical sector commander	After 15 minutes
3x rapid response car for physician response unit	3x physician, 3x paramedic	1x after 8 minutes 2x after 15 minutes
5x ambulance	10x paramedic	After 15 minutes

[1] A fire company consists of the following units: 1x command vehicle, 1x fire engine, 1x tanker, 1x ladder

1x equipment container for mass casualty incidents	2x firefighter	After 15 minutes
1x ambulance bus	2x firefighter	After 15 minutes
Federal agency of technical relief (THW)		
1x car	1x structural engineer / representative of THW	After 35 minutes
1x technical platoon[2]	22x THW volunteer	After 60 minutes
1x special unit search type A	9x THW volunteer, 4x rescue dog	After 60 minutes
1x special unit broaching	9x THW volunteer	After 60 minutes
Police service		
3x patrol car	6x police officer	After 8 minutes
Others		
1x energy supplier service truck	2x service personnel	After 30 minutes

Conduct of the Tabletop Exercise

The authors conducted the tabletop exercise on a diorama (1.20m x 2.00m) in the Laboratory for Major Emergency Incidents at TH Köln. The tabletop exercise diorama (shown in Figure 2) displayed a complex of several streets with residential and commercial buildings (scale 1:87). The incident site was visualized by a realistic debris model (shown in Figure 3), which had been prepared based on the scenario description from the exercise concept. Tactical units were represented in the simulation by model vehicles and figures.

Figure 2. Tabletop Exercise Diorama

Figure 3. Debris Model "Gas Explosion"

An experienced emergency response manager with brigade commander qualification from a fire department, who is also active in higher education for future emergency response managers at TH Köln, moderated the exercise (hereinafter referred to as "instructor"). This should increase the participants' acceptance of the exercise and make sure that the exercise was run according to its intended purpose. The instructor decided on his own on script adaptions necessary for continuing the exercise. To research information in the exercise script and document decisions deviating from the planned procedure, an assistant was available to the instructor. Furthermore, the assistant released information requested by the participants (e.g. results of a mobile phone location). Due to the amount of information provided by the FOUNT[2] system, an additional assistant was assigned for this purpose.

The focus of the exercise was on the activities in the search and rescue sector and the safety sector as well as on the activities of the incident commander and the FOUNT[2] operator. Two rounds of the exercise were performed with eight participants in total. In each round, the roles of incident commander, search and rescue sector commander, safety sector commander and FOUNT² operator were performed by different emergency response managers. The medical sector and the logistics sector as well as the tasks of the command staff were performed by participants, but only to enable the others to interact with them. The same people played these roles in each round. The tasks of the structural engineer and the representative of the federal agency of technical relief were combined

[2] The technical platoon consists of the following units: 1x personnel transporter, 2x rescue truck, 1x truck with wooden shoring system

and were also performed by one person in both rounds. A total of twelve participants were involved in the exercise.

Prior to the start of the exercise, all participants waited outside the laboratory so that they could not see the situation displayed on the diorama. The exercise began when the first participants entered the laboratory. The instructor first transmitted the information available at the time of the alarm that could not be displayed on the diorama (type of call, time, weather etc.). Then the participants approached the diorama. From this point on, the participants took over the incident response, discussed their reconnaissance results, decisions and measures, presented them on the diorama and received additional information from the instructor. At predefined times, further participants and simulated response units entered the exercise. Each round ended when all trapped victims had been located. At the end of a round, a debriefing was held with the participants.

Observation Procedure

To document the tabletop exercise and the debriefing, audio and video recordings as well as observers were used.

Observers

To reduce possible distractions during the exercise, four of the seven observers performed their task from a separate observation room. Three of the observers were deployed to the laboratory. The perspectives of all video recordings were transmitted live to the observation room and displayed with video projectors in front of the observers. The audio recording in stereo was transmitted as well. The coordination of the observers was carried out by the observation management, which was also based in the observation room. Arrangements between personnel in the observation room and in the laboratory were possible via telephone.

The task of the observers was to document the flow of information and the decisions being made by the participants. Four observers were assigned to positions in advance. One observer documented the search for trapped victims. Two other observers had no specific objective and documented the entire exercise. An objective could be assigned to them at any time during the simulation. Observations were documented by recording the time on a prepared observation sheet. Table 3 shows the location of the observers as well as their assignment to the position observed. The selection of observers was based on their personal experience in the field of emergency response. In addition, the observers were prepared for their task in the preparation phase of the exercise by participating in a trial run. During the trial run, each observer performed the position to be observed in order to become familiar with its tasks and procedures.

Table 3. Locations and Assignments of the Observers

	Position observed	**Location of the observer**
Observer 1	Incident commander	Observation room
Observer 2	Search and rescue sector commander	Observation room
Observer 3	Safety sector commander	Observation room
Observer 4	FOUNT² operator	Laboratory
Observer 5	Process of the search for trapped victims	Observation room
Observer 6 and 7	No specific mandate	Laboratory

Audio and Video Recording

Five cameras with wide-angle lenses were set up in the laboratory for audio and video documentation, recording the events from several perspectives synchronously. In the area in front of the diorama, two directional microphones were placed and aligned in such a way that the conversations of the participants could be recorded. To facilitate the observers' tasks in the observation room, a camera also recorded the frontal view on the participants. Figure 4 shows the positions of the cameras and microphones in the laboratory.

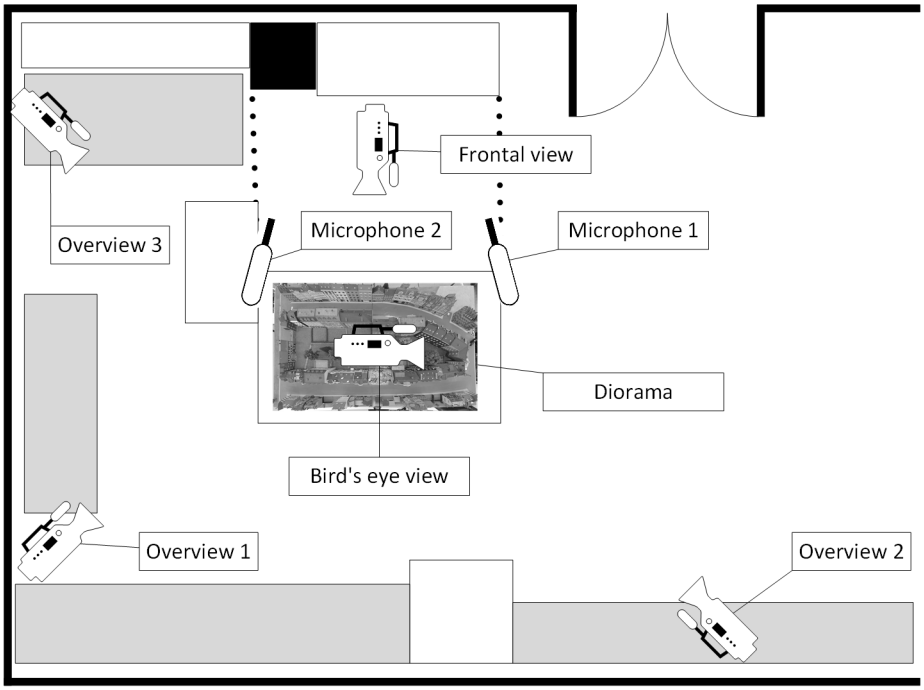


Figure 4. Positions of the Cameras and Microphones in the Laboratory

Debriefing and Data Analysis

In the aftermath of the exercise, the observers summarized their notes in the form of an observation report, which focuses on the main research questions. The authors reviewed those reports and compiled a summary. The audio and video recordings were evaluated and the chronological order of the participants' actions as well as the times at which information was released were documented. Orders, feedback and communicated information were recorded by specifying sender, recipient, time and content. In addition, the participants' debriefings were documented analogously. In a final step, the authors compared the summarized observations to the records.

RESULTS

The first round of the exercise took 1:11 hour, the second round 1:08 hour. Both rounds were carried out without interruption. In the following, the aspects most important for answering the research questions and for assessing the exercise as an evaluation method are listed.

Aspects for Answering the Research Questions

- During both rounds of the exercise, the proposed implementation approach was applied by the participants.
- In both rounds, a regular exchange and a joint discussion of information provided by the FOUNT^2 system (bird's eye overview, bioradar data) took place between the search and rescue sector commander and the FOUNT^2 operator.
- In the first round, the search and rescue sector commander asked the FOUNT^2 operator to independently coordinate his actions with the other search units.
- The FOUNT^2 operator communicated the results of the localization with FOUNT^2 to the incident commander in both rounds via the search and rescue sector commander.
- According to the participants, not all the information presented was relevant to the search and rescue sector commander and the safety sector commander. However, it is useful to be able to retrieve the information as needed.
- According to the participants, the information provided by FOUNT² can be interpreted by a single person who has received sufficient training to operate the system. Nevertheless, the use of several persons for this task can be helpful.
- In addition to the FOUNT^2 system, the participants used other search methods in both rounds.

- Errors or weaknesses in the implementation approach were not observed.

Aspects for the Assessment of the Exercise

- The FOUNT^2 operator had to re-sort the information printouts released in the first round. The labeling of the printouts was not sufficient.
- According to the participants of both rounds, the debris model displayed as well as the conditions on the diorama were authentic and realistic.
- The participants perceived the performance of the tasks of the structural engineer and the representative of THW by one person as problematic.
- In the debriefings of both rounds, the participants emphasized the good cooperation with one another.
- From the instructor's point of view, the participants achieved a comparably good incident response in both rounds.

DISCUSSION

Due to the exercise's boundary conditions, a statement regarding the suitability of the implementation approach can be made for the simulated scenario only. Since the assignment of the FOUNT² system to the technical search methods is scenario-independent, the applicability of the implementation approach to similar incidents with other causes can be assumed.

The assumption that the incident commander, the search and rescue sector commander as well as the safety sector commander arrive on scene at the same time, is fundamentally unrealistic. In reality, the complete establishment of the simulated command and control structure would be delayed. For the conduct of this simulation, however, a more realistic presentation would have had no benefit. Furthermore, this would have jeopardized the establishment of the command and control structure required for the evaluation, as the participants are not sufficiently familiar with the structure specified as the tactical standard. It is assumed that this is caused by the artificiality of this exercise.

The technical realization of the audio and video transmission into the observation room had negative effects on the observers' work. However, the number of microphones was too low. This made it difficult to differentiate between the individual contributions when several participants were talking at the same time. Furthermore, audio and video signals could not be synchronized. The observers perceived this time lag as distracting. This may have had a negative influence on the quality of the observation. In the aftermath of the exercise, however, the video recording could be synchronized with the audio track. Therefore, synchronized audio and video recordings were available for the evaluation. The information contained in the observation reports was verified during the follow-up process.

The representation of the user interface's information in paper form led to a large number of printouts, which had to be managed by the respective participants. It is assumed that the display of the information via the user interface itself will simplify the information management.

CONCLUSION, OUTLOOK AND FURTHER RESEARCH

Answering the Research Questions

1. Which weaknesses/errors of the implementation approach can be identified?

No errors could be identified in the implementation approach. However, it should be kept in mind that only the results of the evaluation of bioradar data should be displayed to managers with read-only access, so that the amount of information is kept manageable. Furthermore, it should be considered to have several persons operate the FOUNT^2 system, as evaluation, operating and communication tasks may have to be performed simultaneously. A crew commander for the FOUNT^2 system could facilitate the coordination with other units. Moreover, it is conceivable that he or she could act as an advisory function for superior commanders.

2. Do the positions within the command and control structures that are addressed directly or indirectly by the FOUNT² system receive the information provided by FOUNT²? Is this information used and forwarded if necessary?

In both rounds, the directly or indirectly addressed functions received the information provided by FOUNT^2. The information was discussed and used to cope with the mission. The information was passed on in joint briefings for all managers as well as in reports of the search and rescue sector commander to the incident commander.

Tabletop Exercise as Evaluation Method

The conduct of the exercise shows that it is possible to simulate a complex incident like a building collapse that requires an extensive command and control structure, using a tabletop exercise diorama. Also, the method used is suitable for testing an approach to implementing information gathering systems in an existing command and control structure.

Additionally, the realized observations show that it is possible to perceive observation orders in a separate observation room using audio and video transmission. Although, the technical realization used can still be improved. For example, the use of personal or position-related microphones could improve observations and expand the possibilities for the evaluation of the exercise.

Also, this study shows that in the context of using a tabletop exercise as an evaluation tool, the conduction of a trial run supports both the detailed exercise script and offers observers the opportunity to prepare for their observation objectives. However, carrying out a trial run requires that the observers have a basic tactical knowledge of the simulated incident response. This knowledge can also facilitate the classification of the perceived observations during the exercise.

Substituting digital devices with printouts appears mostly unsuitable. The excessive number of printouts caused a distraction in the exercise, so that the goal of avoiding a distraction by an unknown digital device could not be achieved completely. In the future, it will be necessary to investigate which form of information display is more suitable.

The participants' feedback also showed that the use of a realistic debris model in combination with an authentic scenario is appropriate to make it easier for the participants to immerse themselves. This could have a positive effect on the validity of the evaluation.

Summary and Outlook

The developed approach of implementing the FOUNT^2 system into the command and control structures in USAR operations can be considered suitable. During the validation of the research results, it has to be evaluated carefully whether the possibility of a read-only access to the FOUNT^2 user interface by the search and rescue sector commander and the safety sector commander offers a tactical added value. The instrument of a tabletop exercise seems to be useful for the simulation of complex incidents for research purposes.

For the further progress of the FOUNT^2 project, findings were obtained for the design of a tactical unit to operate the FOUNT^2 system. Also, new aspects for the optimization of the previous development steps could be identified. The next step is to test the FOUNT^2 system in a real-life exercise and to validate its benefits.

ACKNOWLEDGMENTS

"Fliegendes Lokalisierungssystem für die Rettung und Bergung von Verschütteten" (FOUNT^2, English: Flying localization system for the rescue and recovery of trapped victims), is a research project funded by the German Federal Ministry for Education and Research (Program: Research for civil security – innovative systems for rescue and safety, Grant No. 13N14161 to 13N14167).

REFERENCES

Alexander, D. (2002) Principles of emergency planning and management, Terra, Harpenden.

Ausschuss für Feuerwehrangelegenheiten, Katastrophenschutz und zivile Verteidigung (AFKzV) [Board of Fire Fighting Affairs, Catastrophe Protection and Civil Protection] (1999) Feuerwehr-Dienstvorschrift 100 - Führung und Leitung im Einsatz - Führungssystem [German Regulation 100 – Leadership and Command in Emergency Operations – Command and Control System] – FwDV 100. Available online at https://www.bbk.bund.de/SharedDocs/Downloads/BBK/DE/FIS/DownloadsRechtundVorschriften/Volltext_Fw_Dv/FwDV%20100.pdf, checked on 03/20/2019 [translated version available online at: https://www.sfs-w.de/projektgruppe-feuerwehrdienstvorschriften/vom-afkzv-autorisierte-uebersetzungen.html?no_cache=1&download=fwdv_100_engl_org.pdf&did=74, checked on 03/20/2019].

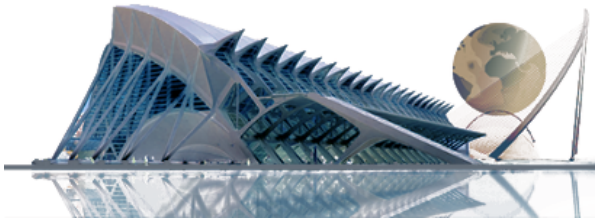
Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (BBK) [Federal Office of Civil Protection and Disaster Assistance], Lehrbereich IV.6 - Strategische Krisenmanagement-Übungen (2011) Leitfaden für strategische Krisenmanagement-Übungen [manual for strategic crisis management exercises], Bonn.

Rempe, A., Klösters, K. and Slaby, C. (2015) Das Planspiel als Entscheidungstraining [the tabletop exercise as decision training], 3rd ed., Kohlhammer, Stuttgart.

Statheropoulos, M., Agapiou, A., Pallis, G. C., Mikedi, K., Karma, S., Vamvakari, J., Dandoulaki, M., Andritsos, F. and Thomas, C. L. P. (2015) Factors that affect rescue time in urban search and rescue (USAR) operations, *Nat Hazards,* 75, 1, 57-69.

van Niekerk, D., Coetzee, C., Botha, D., Murphree, M. J., Fourie, K., Le Roux, T., Wentink, G., Kruger, L., Shoroma, L., Genade, K., Meyer, S. and Annandale, E. (2015) Planning and Executing Scenario Based Simulation Exercises: Methodological Lessons, *Journal of Homeland Security & Emergency Management,* 12, 1, 193-210.

Vereinigung zur Förderung des Deutschen Brandschutzes e. V. (vfdb) [German Fire Protection Association (gfpa)] (2005) vfdb-Richtlinie für Hinweise für Maßnahmen der Feuerwehr und anderer Hilfskräfte nach Gebäudeeinstürzen [gfpa-guideline for instructions for actions of the fire service and other emergency responders after building collapses] - vfdb 03/01:2005-03, VdS Schadenverhütung Verlag, Köln.



ISCRAM 2019
16 TH INTERNATIONAL CONFERENCE ON INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

Track 3.

Ethical, Legal and Social Issues

Chairs

Monika Büscher, *Lancaster University, UK*

Katrina Petersen, *Trilateral Research, TLD*

Caroline Rizza, *Télécom Paristech, Paris, France*

Efficiently allocating safety tips after an earthquake – lessons learned from the smartphone application LastQuake

Laure Fallou
Euro-Mediterranean Seismological Centre (EMSC)
fallou@emsc-csem.org

Laura Petersen
Centre National de Recherche Scientifique (CNRS)
laura.petersen1@gmail.com

Rémy Bossu
Euro-Mediterranean Seismological Centre (EMSC)
CEA, DAM, DIF, F-91297 Arpajon, France
remy.bossu@cea.fr

Frédéric Roussel
Euro-Mediterranean Seismological Centre (EMSC)
roussel@emsc-csem.org

ABSTRACT

In a context of information overload, actors in disaster management are facing challenges to efficiently allocate critical information during a crisis. Based on the empirical experience of EMSC (Euro-Mediterranean Seismological Centre) with its application LastQuake, this paper explores ways to provide safety information in a timely manner, to the people who actually need it. First we introduce the method used to design and implement universally understandable visual safety tips, taking Ethical, Legal and Social Issues (ELSI) into consideration. Then, results on the effective use of the feature are presented. Findings demonstrate the importance of designing universal tools to limit the use of personal data as well as the necessity of developing a multichannel approach for efficient crisis information allocation.

Keywords

Earthquake, Risk reduction, Disaster app, Safety tips, ELSI.

INTRODUCTION

Earthquakes, one of the gravest natural hazards worldwide, annually cause a consequential number of injuries and death around the world. In 2018, over 4 000 casualities were recorded[1]. However, earthquakes *per se* do not harm or kill people; collapsing buildings and hazardous behaviours do (Johnston et al., 2014). Just as quake resistant buildings are necessary to reduce earthquake risk (Rahman, 2017), preventing risky behaviours also efficiently contributes to achieve this goal. Information before, during and after an earthquake has been found to reduce anxiety and increase resilience (Beatson et al., 2014; Bossu et al., 2018; Zhang, 2013). Furthermore, information sharing during every stage of the disaster cycle has been found to be a universal need, leading the Red Cross and Red Crescent Societies to declare that "people need information as much as water, food, medicine or shelter" (IFRC 2005). Thus, citizens must be informed about proper earthquake-related behaviours to adopt.

As earthquakes cannot (to date) be predicted, behavioural information must be sent once the event has occurred. Furthermore, as it usually takes time before trained professionals arrive on the ground, safety information about good behaviour should reach citizens in such a timely manner as to fill this gap (Milliken & Linton, 2016). Regarding information needs *during* a crisis, Ryan found that people expected to receive information about how they should behave and what they should do (Ryan, 2012). Hence, the messages should be sent right after the beginning of the crisis. Moreover, earthquakes occur all over the world, sometimes in border regions and due to

[1] https://www.unisdr.org/archive/63267

the massive development of global tourism, for a given earthquake, people with different cultures and risk culture can be impacted. Thus being able to provide safety tips to all witnesses right after the event regardless of their cultural background appears necessary. One ever more popular means of meeting this information need and reducing earthquake risk is through what are known as "disaster apps".The Euro-Mediterranean Seismological Centre (EMSC) has developped the lastQuake app to detect felt earthquakes and provide information about them. Based on the EMSC team experience,this article then examines the efforts of the Lastquake App to create and implement the sharing of behavioural information to earthquake eyewitnesses via "safety tips". It does so by first presenting a literature review on disaster smartphone applications (apps) and then describing the empirical methodology used by the EMSC, developer of LastQuake. It demonstrates how the "safety tips" were designed and implemented considering Ethical, Legal and Social Issues (ELSI). Then it examines the results of the monitoring system to draw conclusions upon the effective use of these "safety tips." Our findings show that EMSC safety tips were highly used during seismic events and help in educating citizens in general to adopt good behaviours after an earthquake.

DISASTER APPS

When a disaster strikes, people expect to find accurate and timely information on different channels and from a range of actors that they can trust[2]. Often this includes what used to be called "new technologies", aka social media, disaster apps, websites, etc. These tools have created opportunities to efficiently spread and collect information in case of disaster, including earthquakes (Aydin et al., 2016; Bachmann et al., 2015; Beatson et al., 2014; Tagliacozzo & Magni, 2016). While certain of these "new technologies" such as social media do enable one to circulate a large amount of messages to a large audience, they may also create communication challenges. As Hagar (2011) demonstrated, during a crisis, citizens on social media may be facing an information overload as the diverse actors and agencies involved in the response spread, each, an important number of messages. This adds to the difficulty of finding relevant and trustworthy information. In this context of information overload, how can actors in disaster management succeed in passing the right information to the right citizen, the one who needs it?

Disaster apps can be considered as a solution to the information overload problem. A wide range of emergency preparedness and disaster response smartphone apps now exist (Bachmann et al., 2015) and they provide opportunity to directly reach citizens in need. Indeed, smartphones present the strong advantage of enabling a precise localization of the user, through the GPS system (if enabled). Apps are thus efficient tools to directly reach citizens in the affected area, including tourists (Bachmann et al., 2015) who may not know the authoritative local source or may not be able to access information due to language barriers. They enable efficient warnings (Douvinet, 2018) and can be a practical tool to spread critical information about good behaviour to adopt and the ones to avoid, in a timely manner.

However when dealing with crisis information, one must not only think about how to reach the citizen in need but also about the technological and cultural suitability (Steelman et al., 2015). The question of suitability is especially important for disaster apps since a user must "opt-in", or download, the app. Thus, making the app attractive to the users is necessary.

If perceived usefulness and efficiency are key to effective use, trust is also decisive (van Velsen et al., 2013). This implies the need to take ELSI into account. For instance, when using users' localization to efficiently allocate safety instructions, institutions are collecting sensitive and personal data. This should be reflected upon and done in compliance with the law, such as, for instance, the General Data Protection Regulation (GDPR) enforced by the European Union (McDonald, 2016). A study lead by Adhikari et al. (2014) also showed that security and privacy issues can lead to great turnover in apps use. Privacy by design has thus become a key recommendation and even legal obligation, for apps in general, including disaster apps (Jasmontaite & Dimitrova, 2017; Kuner & Marelli, 2017; Kuner, 2018;).

Lastly, when managing a disaster app, it has been proven important to involve users in its development (Kouadio, 2016). It ensures a better understanding of needs and potential variations in use linked to cultural factors.

EMSC'S DISASTER APP: LASTQUAKE

The EMSC has developed a unique and innovative earthquake detection and multichannel information system. It is a perfect blend of crowdsourced data from eyewitnesses and data collected from seismic

[2] IMPROVER EU H2020 project, D4.1, Available at : http://improverproject.eu/2016/06/23/deliverable-4-1-social-resilience-criteria-for-critical-infrastructures-during-crises/

institutes. The system involves websites, social media and the app LastQuake (Bossu et al., 2015). The free and add-free app (available for Android and iOS) is now used in most countries around the world (

Figure 1) especially in all active seismic areas, by about 300 000 people[3]. The LastQuake users' community is composed of earthquake eyewitnesses, citizens with relatives living in seismic areas, as well as by scientists and emergency managers.

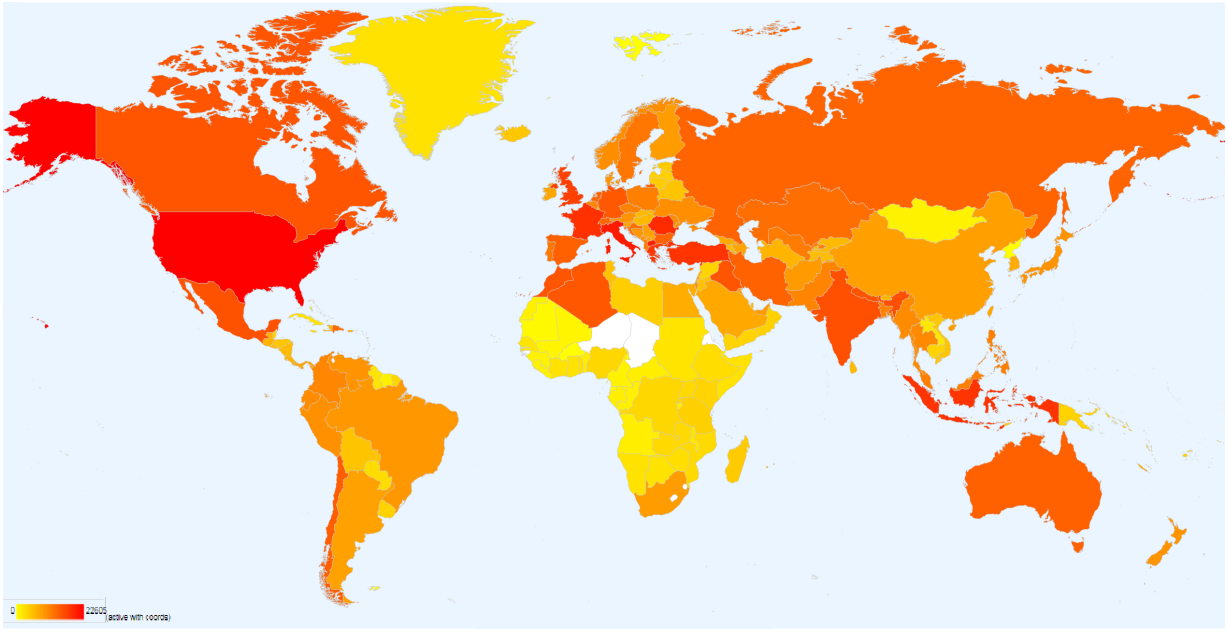


Figure 1. LastQuake users in the world

Through LastQuake, eyewitnesses can share their experience. Through 12 visual pictures, users can report the intensity of what they felt (Figure 2c). The visual thumbnail-based questionnaire has been proven to be more efficient than traditional online questionnaires and increase the number and speed of collected testimonies (Bossu et al., 2017). Users are provided with timely information about felt earthquakes[4] around the world and can read testimonies from those in the area (for a more detailed explanation, see Bossu et al., 2018). Providing information about the earthquake itself (such as the location and the magnitude) but also about its consequences (felt intensity, potential damages,…) actively contributes to reduce anxiety (Bossu et al., 2018).

When navigating through LastQuake, users are offered the possibility to (1) view a list of earthquakes (Figure 2a), (with a colour code corresponding to felt intensity and potential dangerousness), (2) get information on a specific event (Figure 2b), and (3) leave a testimony and even a comment or visual document about an earthquake they felt (Figure 2c and Figure 2d).

[3] The number of app users is in constant evolution due to downloads and uninstallations. However, it is quite stable with around 340 000 users.

[4] It is important to insist on the fact that EMSC focuses on felt earthquakes, as it is assumed that these are the ones that matter most for the public (Bossu, Steed, Mazet-roux, Roussel, & Etivant, 2015)

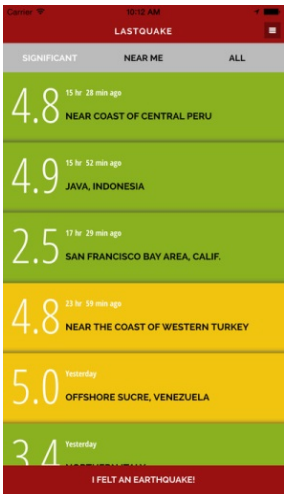


Figure 2a. List of significant earthquake in LastQuake

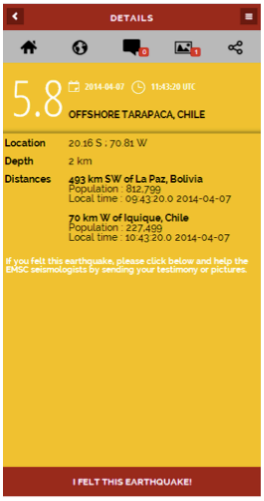


Figure 2b. Earthquake details page in LastQuake

Figure 2c. Felt reports page for testimonies in LastQuake

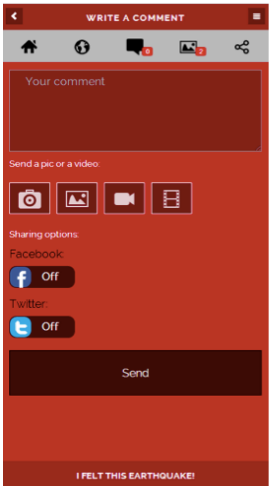


Figure 2d. Collection of open-ended comments, pictures and videos for testimonies in LastQuake

Using the GPS position of the smartphone, EMSC is able to determine the area where the earthquake was felt and thus, which app users may need safety information. A notification system alerts users in the area when a significant earthquake has occured. When a potentially damaging earthquake of global interest happens, a notification is issued for all LastQuake users around the world.

Since its launch in 2014,EMSC had to deal with ELSI when developping the app. Indeed, as a global information tool, it had to suit with various cultural information needs or technological cultures. The app also had to be designed to function even with low internet access. Along with overcome cultural and technological barriers, EMSC always paid attention to only collect necessary data in order to respect users' privacy. Having all stakeholders involved in the design of disaster-related tools has been proven efficient to adress ELSI (Liegl, et al. 2016). EMSC has thus paid attention to consult users regularly as part of the development process.

After the deadly 2015 earthquake in Nepal, EMSC launched an online survey among LastQuake users living in Nepal, India and Bangladesh, as part of a feedback process. For convenience reasons (cost and analysis), the questionnaire was written in English and disseminated through EMSC's Twitter and Facebook accounts, but also through a notification on LastQuake app. Data was collected between 8th and 15th of June 2015, less than two months after the main earthquake. Users were asked about the way they used the app during the crisis, but also about potential improvement. 667 users responded to the survey. 44% of them asked to be provided with "Dos and don'ts", so that they would know how to act after an earthquake. This was the most common request. To meet this need, EMSC developed a series of safety tips, following a methodology described in the next section. It is important to emphasize that this advice does not cover the duration of the shaking itself. Indeed, LastQuake is mostly used right *after* an earthquake.

METHODOLOGY

This paper follows a two steps methodology. First is presented the empirical approach followed by EMSC to develop and implement the "safety tips" through the disaster app LastQuake. In a second part the effective use of this feature is monitored and analysed.

DESIGN AND IMPLEMENTATION OF "SAFETY TIPS"

EMSC undertook the following steps:

1. Benchmark of safety rules for post-earthquake behaviours from key players
2. Develop a way to represent the chosen "safety tips" on a smartphone
3. Assess the understanding of the "safety tips" via an online survey and twitter conversation
4. Redesign the "safety tips" based on feedback
5. Implement them on the LastQuake app

Benchmark

Developing the safety tips required finding universal ones, which would be accurate in all areas of the world. Post-earthquake safety tips were identified through a benchmark of commonly agreed upon safety rules. The benchmark included advice from official seismic institute, NGOs, and some national disaster management agencies. The five most commonly used were selected: (1) Do not stay inside, (2) Stay away from buildings (3) Call emergency services only for serious injuries (4) When possible text your relatives rather than call them and (5) Stay informed.

Design

Because LastQuake is used in 191 countries, it was necessary to implement the advice in a way that transcended national, geographical, linguistic and cultural "borders" and could be understood regardless of literacy level. It was of prior importance to be able to reach also under-represented populations, including the poorest and people who have limited access to mainstream media (Akhgar et al., 2017). The messages had to be shared in a user-friendly way and thus shouldn't induce fear (Bean et al., 2016).

It was found out that in case of disaster, language-independent communication helps to improve the understanding and reduces the ambiguity of messages (especially those linked to semantic interpretation) (Fitrianie & Rothkrantz, 2007). Moreover, not all languages use the same space frame. For instance words like "up" "across" or "between" don't always have equivalents in Himalayan languages (Margetta & Fitzgerald, 2016). It has also been found that an Australian Aboriginal language does not use any egocentric coordinates (such as on the left), but only cardinal directions ("to the East" for instance) (Deutscher, 2010). Because language and geo-spatial perception are strongly linked, this makes safety instructions difficult to translate (Margetta & Fitzgerald, 2016). Moreover, with between 100 and 115 distinct languages spoken within Nepal's borders alone, it would be impossible for EMSC to translate a document into so many languages. Using visual communication is thus a good alternative to textual communication. Moreover, cartoons have been found to be an efficient way to communicate in the aftermath of a disaster (Chae et al., 2014) and to be understood in a quite universal way. For these reasons, added to the previous success of visual thumbnails to collect felt reports mentioned above, EMSC opted for designing visual, cartoon safety tips.

EMSC collaborated with an illustrator who turned these five principles into cartoons. Despite the universality constraint (inlcuding the representation of a building for instance), the design was also dependent on the average screen size of mobile device which is rather small. It required drawing cartoons with few details so that they could appear clearly on small mobile screens. To ease comprehension, the safety tips were created following a "do & don't" opposition. This was also, as previously stated, the desire of LastQuake users. However, creating a culturally indifferent do & don't system is not feasible, as ticks and checkmarks have been found to be highly cultural and linked to the education system[5]. Colours were also found to have different meaning. They are not understood the same way everywhere around the globe, depending on cultural factors. For example, in Japan, red is associated with blood, passion, self-sacrifice and strength whereas it is associated with "communism" in Russia or with "love" in western cultures (Bortoli & Maroto, 2001). Despite the difficulties in finding universally accepted codes for "dos" and "don'ts", it was decided to follow the ISO standard for no, a red circle with a slanted cross[6]. While no such standard exists for yes, a green check mark was seen as a good opposition to the no. Red and green were chosen based on the universality of traffic lights for "stop" and "go". The assertion was that combining both the marks and the colours will help the user to understand which picture is what should be done, and which one represents the behaviours to avoid.

Evaluation

Data Collection

In order to evaluate the understandability of the visual safety tips, EMSC launched an online survey. Overall, between the 5th of September and the 2nd of November 2016, 776 answers were collected. Respondents come from 79 different countries (11% from Italy and another 11% from the United States of America). 75% of them use LastQuake. Due to the sample size and dissemination method, the sample is not representative of the world population. 63% of the respondents are men, and 76% are highly educated (University, college or higher). 93% of respondents have already experienced an earthquake and 66% feel exposed or strongly exposed to seismic risk.

[5] https://separatedbyacommonlanguage.blogspot.fr/2007/03/ticks-and-checkmarks.html
[6] http://www.iso.org/iso/graphical-symbols_booklet.pdf

For each set of "do and don't" images (Figure 3), respondents were asked to choose among a list of sentences which one corresponded to their first understanding of the picture.

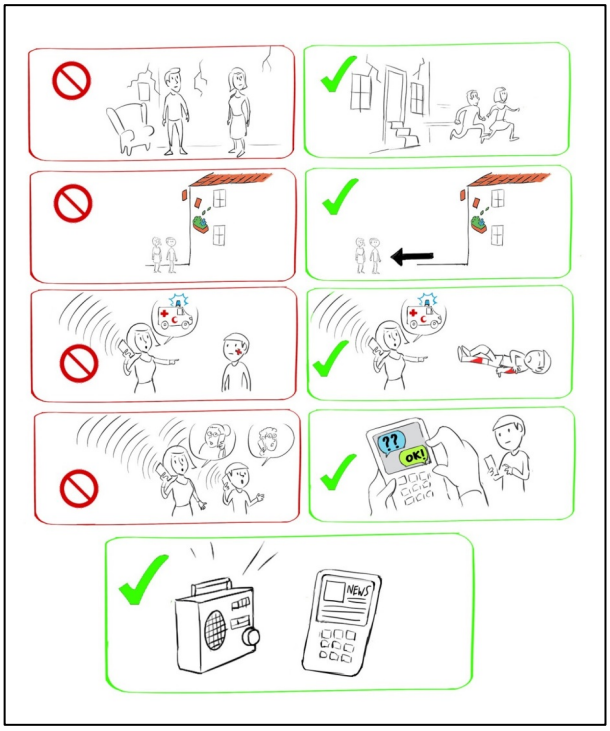


Figure 3. First version of LastQuake safety tips

Results

Overall the safety tips were highly understood by respondents, between 97% ("stay informed") and 85% ("Call emergency services only for serious injury").

Two elements can partly explain why understanding rates were so high. First of all the respondents had, in their majority, already experienced an earthquake. We can then suppose that they are, to a certain extent, aware of this advice. Moreover, in order to facilitate the data analysis EMSC chose to propose some meanings, which may help respondents and guide their understanding. The safety tips were found to be understood universally among the respondents, even if 79 nationalities as diverse as Afghans, Austrians or American were represented. Due to these high rates, no significant difference was found depending on nationality, gender, age, education level, or felt exposure to earthquakes.

Still, few misinterpretations were identified. For instance, for safety tip #1 (first pair of images on Figure3), some people thought they had to run out of the building, and for safety tip #3 (third pair of images on Figure3), 12% of the respondents understood "I should call emergency services for any injury" instead of "I should call emergency services only in cases of serious injury".

Redesign

Thanks to the misinterpretations as well as to comments left in the open questions, EMSC and the cartoonist were able to improve the images. Moreover some members of the community helped through a Twitter conversation and gave their opinion and picture drafts for improvement. This led to a co-constructed and validated final version of the safety tips presented below (Figure 4).

Figure 4. Final version of LastQuake safety tips

Implementation

Once designed in partnership with the cartoonist and LastQuake users, the safety tips had to be implemented in the app. The five safety tips are displayed one by one, with the associated do and don't on the screen (Figure 5) and the user can swipe the screen to see another safety tip. Displaying the safety tips one by one, gives a sense of priority and increases the reading comfort for the user as they can see bigger images. It also emphasizes the fact that there are five tips.

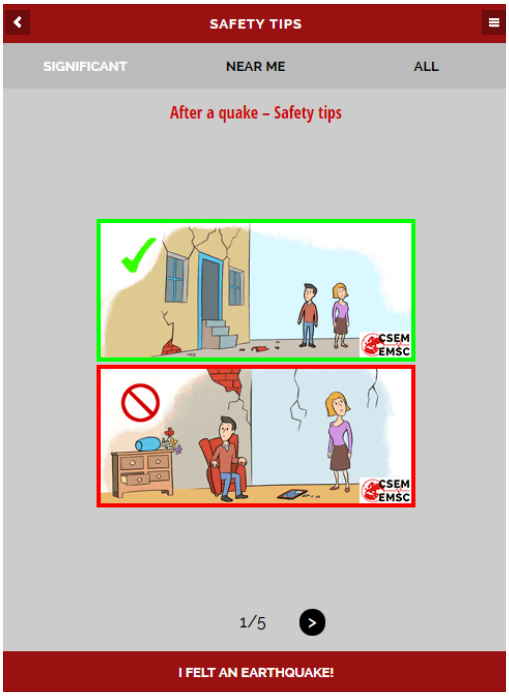


Figure 5. Screenshot of safety tips as displayed in LastQuake app

For preparedness purposes and in order to gain visibility, the safety tips are permanently available for consultation through the LastQuake main menu. However, the goal of this new feature in the app was also to efficiently provide safety tips to users in need when a significant quake strikes. This was made possible thanks to a notification system.

Indeed, for all earthquakes of magnitude 4.5 and above, EMSC determines the area where the expected peak ground acceleration (PGA) was high enough to frighten the inhabitants, i.e. where the shake was the most violent. We only consider LastQuake users whose geolocation falls within this area and then send them the specific safety notification. This safety notification is to be distinguished from the regular LastQuake notification that alerts users in a wider area about the earthquake. For instance, after the M5.7 in Central Italy (18/01/2017), 51237 users received the regular LastQuake notification about the earthquake (magnitude, location) and only 19 users received the safety notification which enabled them to directly consult the safety tips. Indeed only users who potentially felt a violent shake are targeted for the safety notification. The others still have the opportunity to consult the safety tips directly via the earthquake detail page or the main menu.

The underlying idea of the notification range is that citizens feel the immediate need for safety tips when they have felt an earthquake that scared them and/or generated damage. Providing safety tips for every earthquake and all users could thus be counter-productive and become in itself a source of anxiety. This could also lead to an excess of notifications which would decrease the visibility of truly essential information and bother the user, potentially leading to uninstallations.

Regarding ELSI, EMSC adopted the privacy by design approach, using as little personal data as necessary (only the GPS location) and only in the interest of users, namely their own safety. Moreover, no data is shared with any third party.

MONITORING THE EFFECTIVE USE OF THE SAFETY TIPS

In order to monitor the effective use of the safety tips, EMSC collected data to get a more comprehensive overview of how both seismological factors and socio-cultural ones, impact LastQuake use. All data are (and will be) collected with respect to the legislative framework and users' privacy. For instance, for each consultation of the safety tips, EMSC monitors if the user accessed them through the main menu, the notification or the earthquake detail page. EMSC monitored safety tips use between 15 February 2017 and 30 May 2018. Overall, they were consulted 73 874 times by 32 198 unique users from 175 different countries**.** This confirms a general and global interest for the feature.

The vast majority (97.4%) of users who consulted the safety tips found them through LastQuake main menu. 2.4% accessed them through the seismic events page and 0.2% have taken advantage of a safety notification to consult this timely advice. This is partly due to the fact that few earthquakes met the safety notification launch criteria. Moreover, a high shaking zone statistically has a relative small size leading to a slim chance to have users in this zone. During the studied period, 539 earthquakes met the criteria to initiate a safety check, but only 57 actually issued at least one safety notification due to the small size of the expected high shaking area, to the low number of LastQuake users in the region or to the low density of population. In 89% of the cases no notification was sent. This coincides with the idea that safety notifications are designed for rare, potentially frightening or destructive seismic events. Overall, 1 382 users have received a safety notification including a link to the safety tips. 7.8% of them have actually taken advantage of this feature to get advice on good behaviour to adopt.

The monitoring system also enabled to evaluate if users were consulting the five pieces of advice. We consider as complete a visit during which the user actually went through the 5 safety tips and didn't close the page before seeing the whole content. Results revealed that among all the views, only 33% are complete. Users who access the safety tips through an event page were found to be more interested in this advice. 39.5% of them consulted the safety in a complete way, against 33.4% when accessing via the main menu. We can assume that most users who access the safety tips through the event page are potential witnesses and thus directly concerned by the earthquake. They have an immediate interest for information about safe behaviours to adopt.

The number of visits on the safety tips page is to be compared with the total number of uses of the app in the given country. On average, 3.7% of the sessions on LastQuake include a visit on the safety tips page (whether or not the visit is triggered by a felt earthquake). However, significant and interesting differences can be noticed.

Countries such as Iran or Mexico for instance have a much higher safety tips consultation rate than Italy or the U.S.A. (Figure 6.). This goes along with the fact that the USA generates 10% of the total traffic on the app, but only 4% of the visits on the safety tips pages. On the contrary, Mexico issued nearly 18% of the safety tips visits but contributes only 4.8% of the total traffic.

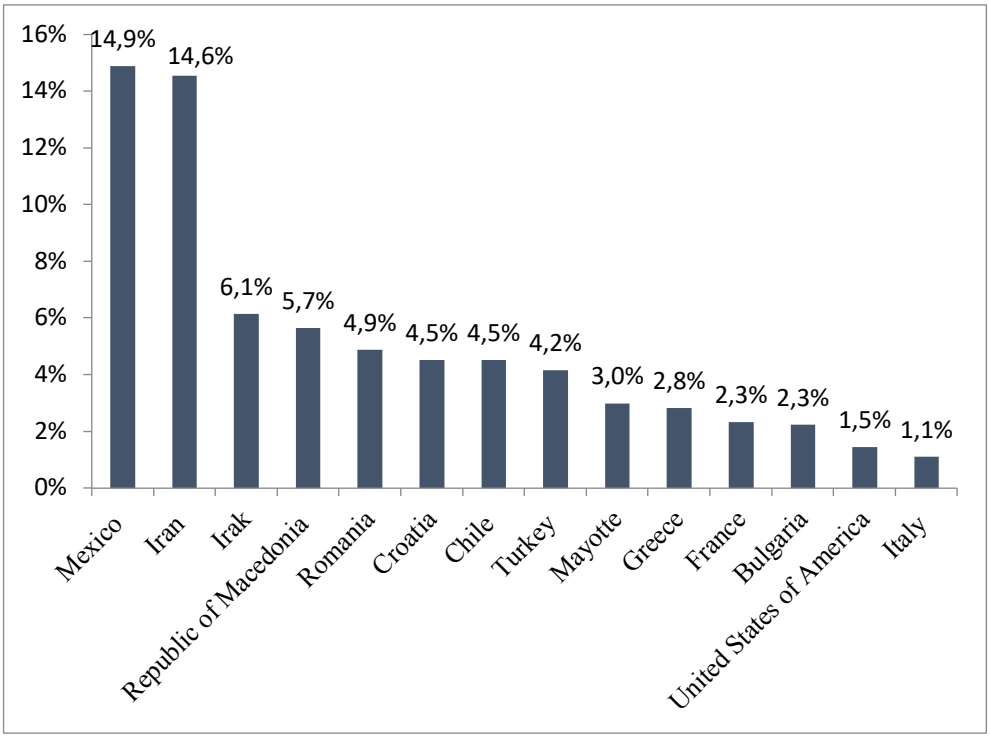


Figure 6. Percentage of connections to LastQuake which include a visit on the safety tips page, per country

DISCUSSION

The safety notification was designed to reach users located in the potentially affected area after a potentially damaging earthquake. Fortunately, few users are concerned by this type of alert. Nevertheless, during less frightening seismic events, many users still accessed the safety tips through the main menu and through the seismic event page. This proves that notifying users based on their localisation is useful but not sufficient to meet all users' needs and confirms that they should be accessible in various ways in the app.

Bossu et al. (2017) have already observed how LastQuake use varies along with seismic factors such as magnitude and felt intensity. Additional data would be necessary to study how these parameters impact on safety tips views. However, a cultural dimension can also explain these variations. Significant differences were found among the 23 countries with a high number of visits (500 minimum). Users from Iraq, Chile, Macedonia and Italy were found to proportionally visit more incompletely the safety tips, contrary to British, Bulgarians, Iranians, and French people living on the Island of Mayotte, found in the Indian Ocean. Mayotte and Great Britain are areas where seismic activity is rare, and thus where inhabitants are not used to earthquakes. This can explain a higher need for information. However, all the other countries are characterized by relatively frequently felt earthquakes. Risk culture and risk perception could thus explain variations of seriousness in the way people use this prevention tool. Depending not only on what other material of this type they can access in their language but also on general interest for risk prevention, users may not show the same involvement in their safety tips exploration.

The differences in the proportion of users' examining the safety tips in comparison to number of users' per country could also be linked to cultural factors, risk perception, and risk culture. For instance, perceived earthquake preparedness in Iran or Mexico may be lower than in Italy or Greece. Risk culture, may also vary between these countries and explain a different appeal for safety advice (Dressel, 2015). Moreover, nationality

has been found to influence expectations in regards to crisis communication (Petersen, et al. 2017). In countries where the needs for safety advice are high, EMSC safety tips help fill the expectation gap regarding prevention. Furthermore, Mexico and Iran, for which consultation rates are substantially higher, have both faced damaging and deadly earthquakes during the studied period. This may have raised the interest for safety tips more largely. More data is necessary to compare whether during earthquakes of this type, safety notifications are proportionally more used.

The fact that most users visit the page simply when navigating on the app implies that safety tips are also useful to raise preparedness. Results suggests that after a felt earthquake, there is a window for prevention, whether for locals who need timely information, or for other users who showed interest in the event. These teachable moments are strong opportunities for efficient prevention (Reynolds and Seeger, 2005; Tan and Maharjan, 2018). Indeed, after a destructive earthquake largely reported in the news or on social media, communities may experience what Gerome Truc calls *concernment* (Truc, 2017). This refers to the strong interest and emotional sharing that a person can experience after a disaster even if he or she wasn't directly involved into. During and after the event, concerned people focus their attention on disaster related news and are willing to get information and take action.

Overall, to better consider ELSI and technological cultures[7] but also the different phases of disaster management, a multichannel approach is necessary. Disaster apps must be considered as part of an ecosystem formed with other technologies such as social media, websites and messaging apps. Indeed, only a fraction of the local audience reached by EMSC launch LastQuake after an earthquake, and reach rates are higher on other tools such as the Twitter account and websites (Bossu et al., 2018). To efficiently address information allocation challenges, it is vital to spread information on various platforms, to push them through notifications when necessary, but also to have them available at all time for preparedness purposes. Thus, future work includes the expansion of the publication of safety tips on EMSC Twitter feed. The work undertaken by EMSC, along with the lessons learned, will also be carried on with the design and implementation of tsunami safety tips.

The example of the safety tips implementation illustrates that ELSI have to be adressed when conceptualizing and designing the tool. For instance, it enabled the EMSC to set up understandable visual advice. However, monitoring the use after the implementation is also essential in order to identify other ELSI linked to the effective cultural use. The challenges identified above will be reflected upon by the EMSC.

Limitations

True universality of EMSC's safety tips was not able to be determined due to limitations of questionnaire-based research. Indeed, when responding to a questionnaire, people often use snap judgement and may be influenced by emotional or contextual factors (Schwarz & Stack, 1999). It should also be noted that the use of Facebook, Twitter and the LastQuake app to distribute the questionnaire was likely to have skewed the sample in favour of those who used the Internet, social media and EMSC's app on a regular basis. EMSC does not collect demographics about its users, leading to a lack of knowledge about the typical user profile. However it is highly possible that users are not representative of the general population in terms of gender, age and social standing, adding to the questionnaire limitations. A qualitative survey on how users actually used the safety tips could help complement the analysis and give insights on how various factors such as education level, income level or quality of the internet access can influence the understanding and assimilation of this tool. Whether the user lives in a rural or dense urban area could also impact its perception of the advice relevance.

Finally, the efficiency of safety tips is complex to approach as inappropriate behaviors are hard to measure when they are avoided. Further, even if the safety tips have indeed been consulted, one cannot tell if lives were indeed spared or if the appropriate behaviors were taken.

CONCLUSION

In order to address both the safety information allocation problem, and a strong users' request, EMSC designed universal visual safety tips and implemented them in its mobile app LastQuake. The design process included a benchmark of safety rules for post-earthquake behaviours from key players, a reflection on how to convey this

[7] This is further developed in CARISMAND D3.1, available at : http://s.carismand.eu/p/c/a/carismand-d-03-01-ls2017-01-770.pdf

advice in a visual and culturally neutral way, and finally an assessment of the comprehension of the first version. Through this co-constructed material, EMSC took up the challenge to design totally understandable safety tips, using no words. They were then implemented in the app, carefully taking into consideration ELSI. Thanks to these safety tips, LastQuake efficiently allocates the right information to the right person at the right time. Users are reminded of the most important safety guidelines to be followed, in order to minimize additional damage and risky behaviours. Visual communication proved to be an efficient way to overcome language barriers, which is crucial in the era of mass tourism and especially for earthquakes, which strike without regard to geopolitical and cultural borders. In over a year, more than 32 000 users have been reached and educated about good practices.

Regarding ELSI, it demonstrates that it is possible to use as little personal information as GPS position to provide useful information to the person in need. By designing universally understood safety tips it prevents one from needing to collect additional personal data which would be necessary to have a more personal, adaptable message. However, after such earthquakes, there is also a window for prevention and it is not only affected citizens who are interested in safety advice. This, along with EMSC empirical experience with providing safety tips reveals the crucial necessity for a multichannel approach when providing critical information after an earthquake.

Overall, developing universal visual post-earthquake safety tips and efficiently allocating them to people in need actively contributes to risk reduction. But apps are not the panacea in terms of alerting and providing critical information. Lessons learnt from LastQuake experience about the multichannel system could be extended to other types of disasters and actors, including official institutions.

ACKNOWLEDGMENTS

Part of the results presented in this paper was developed within CARISMAND project. The CARISMAND project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 653748.

REFERENCES

Adhikari, R., Richards, D., & Scott, K. (2014). Security and Privacy Issues Related to the Use of Mobile Health Apps. *25th Australasian Conference on Information Systems (ACIS 2014)*, (Schulke 2013), 1–11.

Akhgar, B., Staniforth, A., & Waddington, D. (2017). *Application of social media in crisis management*. *Express Computer* (Springer).

Aydin, C., Tarhan, C., Ozgur, A. S., & Tecim, V. (2016). Improving Disaster Resilience Using Mobile Based Disaster Management System. *Procedia Technology*, *22*, 382–390. https://doi.org/10.1016/j.protcy.2016.01.027

Bachmann, D. J., Jamison, N. K., Martin, A., Delgado, J., & Kman, N. E. (2015). Emergency Preparedness and Disaster Response: There's An App for That. *Prehospital and Disaster Medicine*, *30*(5), 486–490. https://doi.org/10.1017/S1049023X15005099

Bean, H., Liu, B. F., Madden, S., Sutton, J., Wood, M. M., & Mileti, D. S. (2016). Disaster Warnings in Your Pocket: How Audiences Interpret Mobile Alerts for an Unfamiliar Hazard. *Journal of Contingencies and Crisis Management*, *24*(3), 136–147. https://doi.org/10.1111/1468-5973.12108

Beatson, A., Buettner, A., & Schirato, T. (2014). Social Media, Crisis Mapping and the Christchurch Earthquakes of 2011. *MEDIANZ: Media Studies Journal of Aotearoa New Zealand*, *14*(1). https://doi.org/10.11157/medianz-vol14iss1id105

Bortoli, M. De, & Maroto, J. (2001). Colours Across Cultures: Translating Colours in Interactive Marketing Communication. *Proceedings of the European Languages and the Implementation of Communication and Information Technologies (Elicit) Conference* . Retrieved from http://globalpropaganda.com/articles/TranslatingColours.pdf

Bossu, R., Landès, M., Roussel, F., Steed, R., Mazet-roux, G., Martin, S. S., & Hough, S. (2017). Thumbnail-Based Questionnaires for the Rapid and Efficient Collection of Macroseismic Data from Global Earthquakes. *Seismological Research Letters*, *88*(1). https://doi.org/10.1785/0220160120

Bossu, R., Roussel, F., Fallou, L., Landès, M., Steed, R., Mazet-Roux, G., … Petersen, L. (2018). LastQuake: From rapid information to global seismic risk reduction. *International Journal of Disaster Risk Reduction*, *28*(February), 32–42. https://doi.org/10.1016/j.ijdrr.2018.02.024

Bossu, R., Steed, R., Mazet-Roux, G., Etivant, C., & Roussel, F. (2015). The EMSC tools used to detect and diagnose the impact of global earthquakes from direct and indirect eyewitnesses' Contributions. *ISCRAM 2015 Conference Proceedings - 12th International Conference on Information Systems for Crisis Response and Management*, (October 2016). Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84947811530&partnerID=tZOtx3y1

Bossu, R., Steed, R., Mazet-roux, G., Roussel, F., & Etivant, C. (2015). The key role of eyewitnesses in rapid impact assessment of global earthquakes. In *Earthquakes and their impact on society* (p. 2711).

Chae, J., Thom, D., Jang, Y., Kim, S., Ertl, T., & Ebert, D. S. (2014). Public behavior response analysis in disaster events utilizing visual analytics of microblog data. *Computers and Graphics (Pergamon)*, *38*(1), 51–60. https://doi.org/10.1016/j.cag.2013.10.008

Deutscher, G. (2010). Does Your Language Shape How You Think ? *The New York Times*, pp. 1–10. Retrieved from http://www.nytimes.com/2010/08/29/magazine/29language-t.html?pagewanted=all

Douvinet, J. (2018). *Alerter la population face aux crues rapides en France : compréhension et évaluation d'un processus en mutation*. Université d'Avignon.

Dressel, K. (2015). Risk culture and crisis communication. *International Journal of Risk Assessment and Management*, *18*(2), 115–124. https://doi.org/10.1504/IJRAM.2015.069020

Fitrianie, S., & Rothkrantz, L. J. M. (2007). A Visual Communication Language for Crisis Management. *International Journal*, *12*(2), 208–216.

IFRC. (2005). *World disasters report. Focus on information in disasters* (Vol. 53). https://doi.org/10.1017/CBO9781107415324.004

Jasmontaite, L., & Dimitrova, D. (2017). Online Disaster Management: Applicability of the European Data Protection Framework and Its Key Principles. *Journal of Contingencies and Crisis Management*, *25*(1), 23–30. https://doi.org/10.1111/1468-5973.12142

Johnston, D., Standring, S., Ronan, K., Lindell, M., Wilson, T., Cousins, J., … Bissell, R. (2014). The 2010/2011 Canterbury earthquakes: context and cause of injury. *Natural Hazards*, *73*(2), 627–637. https://doi.org/10.1007/s11069-014-1094-7

Kouadio, J. (2016). *Les technologies smartphone comme outils d ' aide à l ' alerte face aux crues rapides en France : Expérimentations dans le Vaucluse et le Var To cite this version : Les technologies smartphone comme outils d ' aide à l ' alerte face aux crues rapides en F*. Univerité d'Avignon et des Pays du Vaucluse, France. Retrieved from https://tel.archives-ouvertes.fr/tel-01513549/document

Kuner, C. (2018). International Organizations and the EU General Data Protection Regulation. *Ssrn*, (20). https://doi.org/10.2139/ssrn.3050675

Kuner, C., & Marelli, M. (2017). Handbook on Data Protection in Humanitarian Action. *Geneva: International Committee of the Red Cross*, 1–164. https://doi.org/S0264-410X(05)00973-4 [pii]\r10.1016/j.vaccine.2005.09.020

Liegl, M., Boden, A., Büscher, M., & Oliphant, R. (2016). Designing for ethical innovation : A case study on ELSI co-design in emergency. *Journal of Human Computer Studies*, *95*, 80–95. https://doi.org/10.1016/j.ijhcs.2016.04.003

Margetta, R., & Fitzgerald, C. (2016). Language and earthquakes. Insights in disaster response. Retrieved from https://www.nsf.gov/discoveries/disc_summ.jsp?org=NSF&cntn_id=138469&preview=false

McDonald, S. M. (2016). Ebola: A Big Data Disaster - Privacy, Property, and the Law of Disaster Experimentation. *The Centre for Internet and Society*, (2016.01). Retrieved from http://cis-india.org/papers/ebola-a-big-data-disaster

Milliken, J., & Linton, D. (2016). Prioritisation of citizen-centric information for disaster response. *Disasters*, *40*(3), 476–493. https://doi.org/10.1111/disa.12168

Petersen, L., Fallou, L., & Serafilnelli, E. (2017). Public expectations of social media use by critical infrastructure operators in crisis communication. In *Proceedings of the 14th ISCRAM Conference*.

Rahman, M. H. (2017). Earthquakes don't kill, built environment does : Evidence from cross-country data. *Economic Modelling*, (August), 1–11. https://doi.org/10.1016/j.econmod.2017.08.027

Reynolds, B., & Seeger, M. (2005). Crisis and emergency risk communication as an integrative model. *Journal*

of Health Communication: International Perspectives, *10*(1), 43–35.

Ryan, B. (2012). Information seeking in a flood. *Disaster Prevention and Management: An International Journal*, *22*(3), 229–242.

Steelman, T. A., McCaffrey, S. M., Velez, A. L. K., & Briefel, J. A. (2015). What information do people use, trust, and find useful during a disaster? Evidence from five large wildfires. *Natural Hazards*, *76*(1), 615–634. https://doi.org/10.1007/s11069-014-1512-x

Tagliacozzo, S., & Magni, M. (2016). Communicating with communities (CwC) during post-disaster reconstruction: an initial analysis. *Natural Hazards*. https://doi.org/10.1007/s11069-016-2550-3

Tan, Y. J., & Maharjan, R. (2018). What Googling Trends Tell Us about Public Interest in Earthquakes. *Seismological Research Letters*, (January). https://doi.org/10.1785/0220170116

Truc, G. (2017). *Shell shocked: The Social Response to Terrorist Attacks* (Polity).

van Velsen, L., Beaujean, D. J. M. A., & van Gemert-Pijnen, J. E. W. C. (2013). Why mobile health app overload drives us crazy, and how to restore the sanity. *BMC Medical Informatics and Decision Making*, *13*(1), 23. https://doi.org/10.1186/1472-6947-13-23

Zhang, Y. (2013). The effects of preference for information on consumers' online health information search behavior. *Journal of Medical Internet Research*, *15*(11). https://doi.org/10.2196/jmir.2783

What can we learn from a crisis management exercise ?

Trusting social media in a french firefighters' department

Florent Castagnino
Telecom ParisTech
florent.castagnino@telecom-paristech.fr

ABSTRACT

This paper sets out the methodology and the temporary results of an ongoing research project on the use of social media in crisis management (in France). It discusses the benefits and limits to use an emergency crisis exercise for research purposes. It describes an observation protocol and a coding method that could be replicate to survey further exercises. Some possible processing of the observation data is exposed, and further visualizations of the data are still in progress. One of the first analytical results tackles the way Var's firefighters consider social media information. For now, social media seem to be regarded as questionable because they do not easily fit into the organizational routine. At the same time, the awareness of the need to use social media is quite strong. On the analytical level, the paper tries to use sociological concepts to describe and explain some results.

Keywords

Social Media, crisis management exercise, firefighters, methodology

INTRODUCTION

ISCRAM community is of course convinced by the usefulness of social media for EM (emergency management), and bunch of experiments and papers focus on how to really use them, integrate them and to make the most of it (especially with the help of computer-assisted methods). Yet, a lot needs to be done on "what information do emergency dispatchers and first responders really need" (Kropczynski et al. 2018, 2). Beyond the nature of the needed information, this paper focuses on how disturbing it can be for an emergency organization to concretely use new sources of information. All emergency managers are not still convinced that social media information is trustworthy ; even if social media trustworthiness strongly depends on the quality of the data (Tapia et al. 2013), we argue that in our case (a French firefighters' department) a questionable statute is still given to social media data. This un-trustworthiness relies as much on professionals doubt as on organizational routine.

Our research question fits into the agenda set by Elbanna et. al: "much of the research in the area has focused on public use of social media during an emergency as well as how emergency agencies benefit from the data and information generated by this process. However, there is little understanding of what are the operational implications of this public use on emergency management agencies and how does social media either positively or negatively impact these operations" (Elbanna et al. 2019, 112). Using a more sociological analytical framework, this paper tends to show that apart the quality of social media data and the efficiency of technical tools to process them, organizational features may also affect the propensity of emergency professionals to use social media. The paper builds on a collective observation of a crisis management exercise in France.

The paper consists of four sections. Section 1 frames the state of the art. Section 2 presents the exercise objectives and conditions: the exercise was organized by the Var's firefighters' department (France) and is part of a larger research project funded by the French Research Agency. Section 3 describes the observation protocol, building on previous observations made during the European Union Sequana exercise (for the 100-year flood). Section 4 puts forward some temporary results: data analysis is still on progress, as 2 more exercises, some workshops and interviews are to be made with other institutional partners. Section 5 discusses the methodological implications of the use of a simulation for research purposes and proposes to analyse social media as organizational resources. Section 6 draws some conclusions and perspectives that this ongoing project can offer.

STATE OF THE ART

A lot of research has been done on the potential use of social media for crises management (see for example the survey of ISCRAM proceedings from 2004 to 2011, (Grant and Jongejan 2011). Literature first focused on the use of social media by citizens to help each other and how social media could lead to "collective intelligence" , and then on organizational use of social media to communicate to the public , to use citizen-generated content as a new source of information (Denis and Hughes 2012; Starbird and Stamberger 2010) or to better communication between crisis professionals and organizations (Grant et al. 2013; Vieweg et al. 2010). We propose a non-exhaustive state of the art regarding the obstacles in the use of social media be emergency services in order to frame our observations and discuss our first results.

Organizational and professional grounds of social media trust

A positive attitude towards the use of social media has been observed by several studies, either the US (San et al. 2013) and Europe (Reuter et al. 2016; Rizza and Pereira 2014). Indeed, emergency professionals and citizens can use social media instead of traditional media when the latter not available, especially during the beginning of a crisis (Aupetit and Imran 2017). However, studies on the social media use in emergencies has also observed several obstacles: data quality (Tapia et al. 2011, 2013), the credibility of this kind of information (Castillo et al. 2011; Mendoza et al. 2010), the lack of training and guidelines (Hiltz et al. 2014) or the lack of organizational procedures to help managing such information (Kaufhold and Reuter 2017) or unintended consequences of such uses (Rizza et al. 2014). In accordance with those findings, the paper tries to use pragmatic sociological concepts to emphasize the organizational and professional features that can explain the lack of trust towards social media information. The concept of "interessement work" (Akrich et al. 1988; Latour 2005) – the fact that the interest of actors into a new device or procedure is the result of an organizational work that need to be cared of – and the concept of "trials" (Boltanski 2011; Dodier 2005) – which are moments where actors question the factuality of what they are facing to, moments where they mobilize their capacity to critic the reality – are used to describe the partial integration and use of social media information. They provide internalist explications of what is observed: the (lack of) trust is not what explain but is what need to be explained.

EXERCISE OBJECTIVES AND CONDITIONS

General objectives

The researchers team had two main objectives during the crisis management exercise. The first one was to observe how the Firefighters' crisis management integrate (or not) the citizen, both as an information source – especially through social media – and as stakeholders or participants into the management crisis (either as already reckoned volunteers and already organized and identified helpers, or as spontaneous helpers). Secondly, it was to prepare the second year of the research project (called MACIV -*Management of Citizens and Volunteers: social media in crisis situations*), bringing necessary elements to the realization of a new crisis management prototype in the R-IO-Suite software (Benaben et al. 2016)[1]. Indeed, exercises 2 and 3 will partly focus on the capacity of the prototype to improve the citizens integration into the crisis management by improving social media data computer-processing.

The observation was supposed to focus on three main elements: social media as information source, citizen initiatives during crisis, communication towards citizens. Actually, the exercise was organized in such a way that only the first element (social media as information source) was observable.

[1] Here is an online presentation of the R-IOSuite : https://research-gi.mines-albi.fr/display/riosuite/r-IOSuite+Home

Simulation configuration

The *SDIS 83* is the Var's firefighters' department and the simulation was based on a flood scenario in Sainte-Maxime area (south of France)[2]. This firefighters' department is one of the most involved and advanced in France into the use of social media and citizen-generated content for crisis management. The aim of the simulation was to perform their organizational line about social media. The exercise lasted 2 hours (with 2 hours debriefing), took place in several rooms on October 2018. Six researchers-observers were situated into those rooms (see figure 1):

- First there was the CRAU (Centre de Réception des Appels d'Urgence), which is the Department Call Centre, where emergency calls are treated: one observer was here at the beginning of the exercise.
- Then there was the CODIS (Centre Opérationnel Départemental d'Incendie et de Secours), which is the Department Crisis Room, the place where firefighters try to anticipate major interventions. They also give information to public authorities, and they monitor and advice the firefighters' field activity. In this crisis room, there was a special team (2 persons) dedicated to the monitoring of social media, called the MSGU team, (which is the French acronym for Social Media for Emergency Management, SMEM). One researcher was dedicated to observing the MSGU team while another one observed the whole crisis room.
- Firefighters' field activity was also simulated. This activity is supervised by a special officer, the COS, (Commandant des Opérations de secours), the Emergency Operations Commander. One observer was there too.
- Finally, there was the organization room where people simulated external roles (like the public authority, the VISOV – Volontaires Internationaux en Soutien Opérationnel Virtuel – which is the volunteer's association monitoring social media to help first respondents – like the VOST, Virtual Operation Support Team) and oversaw the scenario proceedings. Two researchers where here.

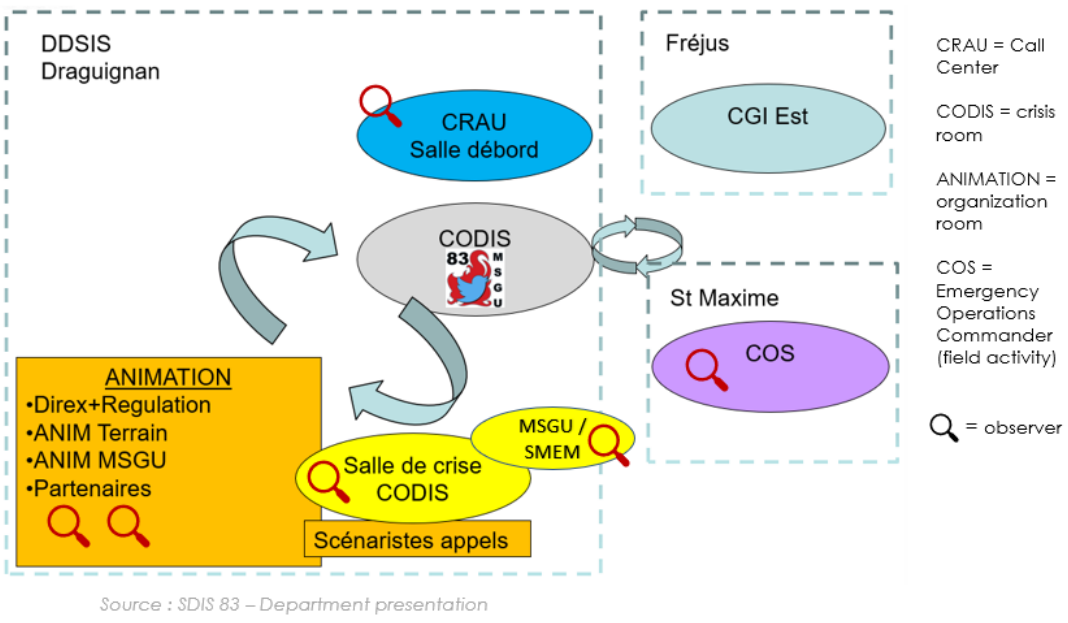


Figure 1. Var's firefighter's department and observers' position

As usual in this firefighter's department, simulation scenario was based on emergency phone calls to which the players must react (see figure 2). In this simulation, a specific social media scenario was added, consisting in a list of tweets (see figure 3): the social media team of the organization room (composed by one VISOV member and one social media analyst of the firefighters' department) "published" them. The Twitter platform was not used: simulated tweets were sent by WhatsApp to the MSGU/SMEM team located in the crisis room. Some tweets were fake or rumor and some contained information that no emergency phone calls could provide (according to the scenario).

[2] SDIS stands for *Service départemental d'Incendie et de Secours* (Local Fire and Emergency Department)

SCENARIO ICM 28 NOVEMBRE 2018 - SME

					Communes	Adresse à donner	Appel à formuler	Intonation animateur
PHASE 1		9h00	inter 1	NP	SME	13 avenue saint exupery residence la riviera SME	1 m d'eau dans la cave	normal
		9h02	inter 2	PR	SME	carrefou market avenue du 8 mai 1945 SME	0,5 m d'eau au niveau de l'administration bcp de matèriel informatique	stressé
		9h04	inter 3	NP	SME	15 rue jules michelet SME	cabonon de jardin qui flotte	normal
		9h06	inter 4	PA	SME	impasse etienne SME	2p personnes dans une vl avec de l'eau au niveau des portieres	paniqué
		9h08	inter 5	NP	SME	residence du golf avenue saint exupery SME	chat dans un arbre dans une propriété ne peut plus descendre à cause de l eau	normal
	Simultané	9h10	inter 6	PR	SME	1 chemin du preconil devant residence les platanes SME	arbre couché sur vp	stressé
		9h10	inter 7	PA	SME	58 rue du plan chantier naval tosato SME	1 famille de 4 personnes sur le toit d'un mobil home à la dérive	paniqué
		9h12	inter 8	PR	SME	pizzeria da pino avenue general leclerc SME	1 personne a mobilité réduite avec l'eau arrivant au niveau des portes du restaurant	stressé
		9h14	inter 9	PR	SME	GB distribution route du plan de la tour SME	arbre menacant de tomber sur 1 garage	stressé
		9h15	inter 10	PA	SME	centre de compostage route du plan de la tour SME	accès impossible ; le proprietaire ne répond pas aux appels	paniqué
		9h16	inter 11	NP	SME	residence le port marine avenue georges pompidou SME	un requérant appelle pour sa voiture qui commence à etre entourée par les eaux	normal
		9h18	inter 12	PA	SME	chemin de basse SME	1 vl emportée par les eaux avec 1 personne sur le toit	paniqué
		9h20	inter 13	NP	SME	18 chemin du preconil residence le maxime	plus d'électricité sur l'ensemble Dans la residence	normal
		9h22	inter 14	NP	SME	parking a cote du leader price route du plan de la tour SME	aire evacuée mais les caravanes commencent à flotter	stressé
		9h24	inter 15	PA	SME	acces domaine les restanques SME	1 voiture dans le fossé et sous les eaux phares allumés	paniqué
	Simultané	9h26	inter 16	PR	SME	LIDL route du plan de la tour SME	quai de livraison innondé	stressé
		9h26	inter 17	PR	SME	maison de retraite des opalines SME	plus d'électricité dans l'ensemble de la maison de retraite	stressé
		9h28	inter 18	NP	SME	4 chemin du preconil residence le soupion SME	eau dans le garage	normal
		9h29	inter 19	NP	SME	menuiserie DAVID route du plan de la tour SME	eau dans la reserve ; mobilier non touché	stressé
		9h30	inter 20	NP	PTR	12 allée du bois d'icard PTR	la requérente ne voit plus les poules dans son poulailler	paniqué
		9h34	inter 21	NP	SME	IGE immobilier rue gabriel péri SME	plus d'électricité	stressé
		9h36	inter 22	PR	SME	garage peugeot route du plan de la tour SME	risque de pollution eau menace stock d'huile et de solvant	stressé
		9h38	inter 23	NP	SME	laboratoire beausset avenue jean jaures SME	10cm dans le jardin	normal
		9h40	inter 24	PR	SME	entrée chemin des saquedes SME	arbres couchés sur vp circulation bloquée	normal
		9h41	inter 25	NP	SME	20 avenue du 8 lai 1945 residence sainte maxime plage SME	fuite niveau du skydome	normal
		9h42	inter 26	NP	SME	entreprise gobino chemin des virgiles SME	10 cm d'eau dans la serre	stressé
		9h43	inter 27	PA	SME	chemin du bouillonnet SME	un agriculteur dans le champs qui est monté sur un pylone erdf ,champs complètement innondé avec fort courant	paniqué
		9h44	inter 28	NP	PTR	camping la laune PTR	camping vide de tout occupant avec 20cm d'eau a l'interieur de ce dernier	normal
		9h45	inter 29	PR	SME	pharmacie du preconil avenue george pompidou SME	arbre qui menace de tomber sur La pharmacie	stressé
		9h46	inter 30	NP	SME	23 avenue georges pompidou residence les terres marines SME	l'eau de la piscine deborde	normal
		9h47	inter 31	NP	PTR	chemin de cros d'entassy PTR	route coupée par la montée du ruisseau	normal

Figure 2. Emergency phone calls scenario

Date JJ/MM/AAAA	Nom	Heure du tweet/post	CONTENU TWEET/POST/IMAGES/VIDEOS	Liens URL	Lieu(x) concerné(s)	Département	Carto	Remarque(s)		Heure de l'input
11/28/2018	Alban	9h04	Fermeture Carrefour Market	https://drive.google.com/file/d/1B55UV_LHM7ffzXbfp_cu8SN-Q-slJ7S1/view	Ste Maxime	83		Photos		9h04
11/28/2018	Léa	9h04	Inondation Rue Michelet	https://drive.google.com/file/d/1nMMyOD0FKQNlswCaav8l51k-K5JmMie8/view	Ste Maxime	83		Photos		9h04
11/28/2018	Alban	9h06	Impasse Etienne, "gens qui vont mourir"	https://drive.google.com/file/d/15vuHG3y4EK0gWWm4ZWy10gHsWTXMD-rY/view	Ste Maxime	83		Photos	URGENT	9h06
11/28/2018	Thomas	9H09	Camping, Propriotéaire sur le toit avec sa famille	https://drive.google.com/file/d/1OaVtfskcye6sMrROjDf0rIzsNi83Dadi/view	Ste Maxime	83		Photos	URGENT	9H09
11/28/2018	Thomas	9h12	Résidence les platanes	https://drive.google.com/file/d/104d_QlbJCdxsT0m5irb8Z0PQqdo0pC57/view	Ste Maxime	83		Photos		9h12
11/28/2018	Thomas	9h20	Résidence du Port, Eau qui monte	https://drive.google.com/file/d/1BIWrBODC1-y-SzZI2Qrq7BCDnR6bz-it/view	Ste Maxime	83		Photos		9h20
11/28/2018	Alban	9H20	Inondation parking d'une carrosserie	https://drive.google.com/file/d/1MJip3_rfm764mZc4cLXK5JxnW6mP8w1V/view	Ste Maxime	83		Photos		9h20
11/28/2018	Thomas	9H19	Route Plan de la tour, Caravane qui flotte	https://drive.google.com/file/d/1uQo7dDJYnaMTqBDFLSRL3VmNL4NWMs6D/view	Ste Maxime	83		Photos		9h22
11/28/2018	Thomas	9h24	Chemin Basse, voiture emportée par l'eau, 1 eprs sur le toit	https://drive.google.com/file/d/1MJip3_rfm764mZc4cLXK5JxnW6mP8w1V/view	Ste Maxime	83		Photos	URGENT	9h24
11/28/2018	Alban	9h26	Fermeture Lidl	https://drive.google.com/file/d/1bRLJvl1Leb2bJr-E4utTZwYFgV6zAAgk/view	Ste Maxime	83		Photos		9h26
11/28/2018	Alban	9H21	Résidence du Soupion, inondation garage	https://drive.google.com/file/d/1SinkcGQZtwgK_8wVcUlIKgbf8FOvySyG/view	Ste Maxime	83		Photos		9h28
11/28/2018	Thomas	9h29	Mer déchainée	https://drive.google.com/file/d/1J5P6uhN-FiSn-Ki-jpxMRX39e1IiHFzD/view	Frejus / St Raphae	83		Photos		9h29
11/28/2018	Léa	9h31	Rumeur Belmondo mort	https://drive.google.com/file/d/1ga6YBTVMFCPI3La6urPBm0ZVJDCQc1tR/view	Ste Maxime	83		Rumeur		9h31
11/28/2018	Léa	9h32	Rumeur Belmondo mort	https://drive.google.com/file/d/1uWvhhfkTAqSYA4oLWr4caNWeNWLC8XsG/view	Ste Maxime	83		Rumeur		9h32
11/28/2018	Thomas	9H29	Inondation jardin, beaussset	https://drive.google.com/file/d/1DrhvagXPrtAcYBlSDUcKXV-na5Q-CDKf/view	Ste Maxime	83		Photos		9h38
11/28/2018	Léa	9H35	Chemin Saguedes, arbre sur la route	https://drive.google.com/file/d/1KZPXijymTKqUlWXXcpC-ERMSUv5HlWWw/view	Ste Maxime	83		Photos		9h40
11/28/2018	Léa	9h43	Rumeur Belmondo mort	https://drive.google.com/file/d/1ii1ZbxxVE-JOORwo4djznb7yYs4gV7Ba/view	Ste Maxime	83				9h43
11/28/2018	Léa	9h44	Caming La Laune, inondation	https://drive.google.com/file/d/1pgYqAW11PzyhqwqEPpXC70x5QmZpUBle/view	Ste Maxime	83		Photos		9h44
11/28/2018	Thomas	9h47	Route coupée à Plan de la tour	https://drive.google.com/file/d/1HdHxQizrW-xZ2uMhjDNDmuQRmQL7W58l/view	Plan de la Tour	83		Photos		9h47
11/28/2018	Léa	9h49	Résidence Helios, Eau dans caves	https://drive.google.com/file/d/1CrUou-_dDWk0Ate6Kss3OnlnsXHmRpMh/view	Ste Maxime	83		Photos		9h49
11/28/2018	Alban	9h49	Chevaux en difficulté	https://drive.google.com/file/d/1i5qEE2cCu1W3LburpgbC7z6-xMGPytsx/view	Plan de la Tour	83		Photos		10H06

Figure 3. Tweets scenario

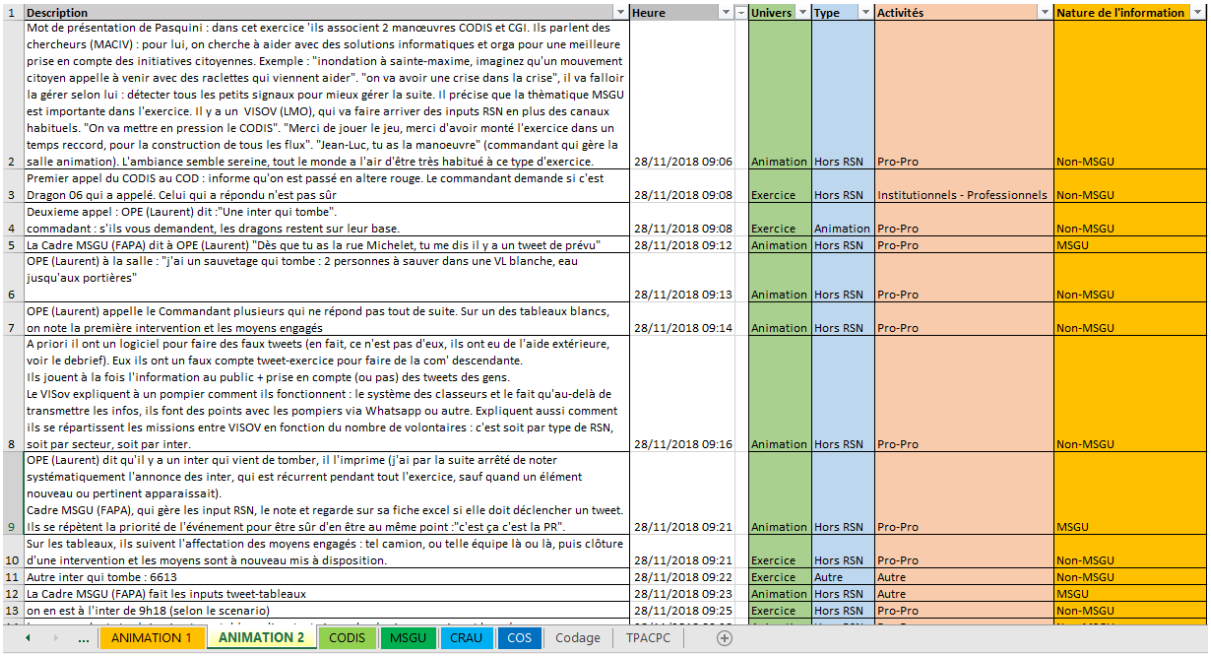
OBSERVATION PROTOCOL

Regarding the observation protocol, we used a method that was freely adapted from the observation made during the *Sequana Exercise* by the Euridice research Consortium (November and Créton-Cazanave 2017). The 6 researchers had the same observation grid, with a timesheet (in order to compile observation lines after the simulation) and a very simple codebook was used, in order to facilitate the data exploration. As the researcher team was interdisciplinary (3 social scientists, 3 computer scientists) and as each researcher had in own specific agenda (beyond the shared general objectives), the choice was made to adopt a descriptive codebook rather than an analytical one.

For each observation line, the observer had to code:

- Whether the observation concerned the players during the exercise, the organization team or the debriefing (*universe*)
- What where the protagonists involved in the interaction observed (*type*)
- If the interaction observed occurred through social media or not (*activity*)
- Whether the interaction was about an information coming from social media (*information nature*)

Observation was made during the simulation and during the debriefing. After the simulation, we made a compilation of each observer's data. To keep it readable, there is an *ad hoc* table sheet for each observer (Animation 1, Animation 2, CODIS, MSGU, CRAU, COS), as figure 4 shows. Further visualizations of the data (e. g., by a time line or by social media inputs) are still in progress.



	Description	Heure	Univers	Type	Activités	Nature de l'information
2	Mot de présentation de Pasquini : dans cet exercice 'ils associent 2 manœuvres CODIS et CGI. Ils parlent des chercheurs (MACIV) : pour lui, on cherche à aider avec des solutions informatiques et orga pour une meilleure prise en compte des initiatives citoyennes. Exemple : "inondation à sainte-maxime, imaginez qu'un mouvement citoyen appelle à venir avec des raclettes qui viennent aider". "on va avoir une crise dans la crise", il va falloir la gérer selon lui : détecter tous les petits signaux pour mieux gérer la suite. Il précise que la thèmatique MSGU est importante dans l'exercice. Il y a un VISOV (LMO), qui va faire arriver des inputs RSN en plus des canaux habituels. "On va mettre en pression le CODIS". "Merci de jouer le jeu, merci d'avoir monté l'exercice dans un temps reccord, pour la construction de tous les flux". "Jean-Luc, tu as la manoeuvre" (commandant qui gère la salle animation). L'ambiance semble sereine, tout le monde a l'air d'être très habitué à ce type d'exercice.	28/11/2018 09:06	Animation	Hors RSN	Pro-Pro	Non-MSGU
3	Premier appel du CODIS au COD : informe qu'on est passé en altere rouge. Le commandant demande si c'est Dragon 06 qui a appelé. Celui qui a répondu n'est pas sûr	28/11/2018 09:08	Exercice	Hors RSN	Institutionnels - Professionnels	Non-MSGU
4	Deuxieme appel : OPE (Laurent) dit :"Une inter qui tombe". commadant : s'ils vous demandent, les dragons restent sur leur base.	28/11/2018 09:08	Exercice	Animation	Pro-Pro	Non-MSGU
5	La Cadre MSGU (FAPA) dit à OPE (Laurent) "Dès que tu as la rue Michelet, tu me dis il y a un tweet de prévu"	28/11/2018 09:12	Animation	Hors RSN	Pro-Pro	MSGU
6	OPE (Laurent) à la salle : "j'ai un sauvetage qui tombe : 2 personnes à sauver dans une VL blanche, eau jusqu'aux portières"	28/11/2018 09:13	Animation	Hors RSN	Pro-Pro	Non-MSGU
7	OPE (Laurent) appelle le Commandant plusieurs qui ne répond pas tout de suite. Sur un des tableaux blancs, on note la première intervention et les moyens engagés	28/11/2018 09:14	Animation	Hors RSN	Pro-Pro	Non-MSGU
8	A priori il ont un logiciel pour faire des faux tweets (en fait, ce n'est pas d'eux, ils ont eu de l'aide extérieure, voir le debrief). Eux ils ont un faux compte tweet-exercice pour faire de la com' descendante. Ils jouent à la fois l'information au public + prise en compte (ou pas) des tweets des gens. Le VISov expliquent à un pompier comment ils fonctionnent : le système des classeurs et le fait qu'au-delà de transmettre les infos, ils font des points avec les pompiers via Whatsapp ou autre. Expliquent aussi comment ils se répartissent les missions entre VISOV en fonction du nombre de volontaires : c'est soit par type de RSN, soit par secteur, soit par inter.	28/11/2018 09:16	Animation	Hors RSN	Pro-Pro	Non-MSGU
9	OPE (Laurent) dit qu'il y a un inter qui vient de tomber, il l'imprime (j'ai par la suite arrêté de noter systématiquement l'annonce des inter, qui est récurrent pendant tout l'exercice, sauf quand un élément nouveau ou pertinent apparaissait). Cadre MSGU (FAPA), qui gère les input RSN, le note et regarde sur sa fiche excel si elle doit déclencher un tweet. Ils se répètent la priorité de l'événement pour être sûr d'en être au même point :"c'est ça c'est la PR".	28/11/2018 09:21	Animation	Hors RSN	Pro-Pro	MSGU
10	Sur les tableaux, ils suivent l'affectation des moyens engagés : tel camion, ou telle équipe là ou là, puis clôture d'une intervention et les moyens sont à nouveau mis à disposition.	28/11/2018 09:21	Exercice	Hors RSN	Pro-Pro	Non-MSGU
11	Autre inter qui tombe : 6613	28/11/2018 09:22	Exercice	Autre	Autre	Non-MSGU
12	La Cadre MSGU (FAPA) fait les inputs tweet-tableaux	28/11/2018 09:23	Animation	Hors RSN	Autre	MSGU
13	on en est à l'inter de 9h18 (selon le scenario)	28/11/2018 09:25	Exercice	Hors RSN	Pro-Pro	Non-MSGU

Figure 4. Observation grid

It important to note that players were aware that this exercise was meant to make observable their use of social media contents. Thus, it cannot be excluded that they had paid more attention than usual to social media information. Indeed, players were aware that some information could only be available on social media. We will discuss later the methodological implications of the use of a simulation for research purposes.

TEMPORARY RESULTS

As mentioned previously, the results presented here are temporary: possible data processing of the observation is presented, and some analytical perspectives are suggested. These feedbacks must be confirmed or disconfirmed with interviews with the players and the organizers involved in the simulation, and with a comparison with the two next exercises.

The main general conclusion that can be highlighted so far concerns the social media as a new information source for emergency managers. Even if the Var's firefighter's department is one of the most involved in the use of social media (only a few French departments, out of around a hundred, have a MSGU/SMEM team), this integration can be considered as *partial*. Indeed, the incorporation of social media into the organizational routine is not yet established or stabilized. This partial or proto-integration can be explained by three main elements. First, social media information is not yet considered as trustworthy as more classical information sources are. Information provided by social media still has a "questionable statute", especially compared to information coming from emergency phone calls or institutional partners. Secondly, this lack of trust can explain, to a high degree, moments of organizational hesitation, fuzziness or uncertainty observed during the simulation. However – and this is the

third point – all these moments are not explained by this questionable statute. Some institutional and professional dynamics, proper to the observed organization, that reinforce these organizational hesitation or uncertainty.

A questionable statute for information collected on social media

This questionable statute was obvious during the afternoon debriefing: players and organizers explained that they had to acculturate themselves to social media and that this acculturation was still an ongoing process (Azzouz 2012). For SDIS members, social media information is not trustworthy enough. This lack of trust is not unfounded: it is based on their everyday work and personal experience. Building on Giddens' work, one can say that social media for emergency management is not yet an "expert systems", i.e. a socio-technical or institutional system that people trust because "it works", but without fully understanding them – a trust backed by their everyday experience (Giddens 1990). In their everyday work, firefighters are confronted to social media information that does not "work" enough. They cannot rely on it without providing an extra task. Social media information is not good enough yet (and this goodness is determined by several factors, among them the fact that the information is actionable or not, Kropczynski et al. 2018), which can explain this untrustworthiness (Tapia et al. 2013).

Nevertheless, Var's firefighters are quite aware of the need to consider information coming from social media. Indeed, during the afternoon debriefing, they remind themselves that in a 2014 real crisis a very important information was only available on social media. This event seems to act like a trigger of this awareness. Following the Actor Network Theory, one could say that there is still a need for an "interessement work" (Akrich et al. 1988). The "interessement work" is a phase in an innovation process which strengthens the association between actors and a new tool or technique (leading to support the structure of the network they form). Actors need to be interested into using or adopting a new device or technology, and this process need to be cared of (Latour 2005). For now, the MSGU/SMEM team of the Var's firefighters' department seems to shoulder this work, with the support of the VISOV. A more systematic organization of this "interessment work" would be welcome to strengthen the awareness around the use of social media.A last hint regarding this social media questionable statute was the discussion –during the debriefing – on the necessity to precise, for each information, whether it is coming from social media. Of course, this would introduce an asymmetry between social media information and other sources of information. This would reinforce the questionable statute of social media information. It appeared to SDIS members that once checked, an information did not need to be tagged as coming from social media. One can interpret this decision as a normalization of the social media as a valuable information source.

…generating moments of hesitation and fuzziness

This questionable statute generated moments of hesitation and fuzziness during the simulation. These are moments where players weren't sure about an information, were wondering if it was accurate or not, etc. During these moments they try to reduce uncertainty, a process which can define risk management (Borraz 2007; Borraz et al. 2007). In these moments, actors mobilized their capacity to doubt or to criticise what they are confronting to (Boltanski 2011).

This result can be illustrated thank to the observation grid. Until now, the exploration of the observation data has been basic and needs to be more systematic. With the observation grid, it is possible to trace (more or less precisely due to a time artefact of the observation grid) the circulation process of a social media information : from the tweet-input by the organization room, to its processing by the crisis room (and especially the SMEM/MSGU team), to its operationalization (or not) on the "field" (= has the information lead to a ground intervention ? an exploratory mission ?). Several social media inputs can be studied. I will elaborate on one example about the "Belmondo's death case" which was a simulated tweet saying that Belmondo (a very famous French actor) died during the flood. According to the scenario this information was supposed to be false, but the players were not aware of it.

INPUT	ANIMATION 1		ANIMATION 2		CODIS		MSGU		COS	CRAU
Belmondo	FAPA et LMO se demandent si il faut envoyer la rumeur en disant que c'en est une. LMO décide de ne rien mettre (rumeur en question : Scoop - mort de JP Belmondo) LMO dit "C'est pas une rumeur c'est un fake" [Quelle différence y voit-il ? L'un plus évident que l'autre ? Après quelques discussions entre chercheurs, il semble que l'usage du terme "fake" soit destiné à une fausse information diffusée intentionnellement, là où une "rumeur" est une information incertaine, à vérifier, diffusée sans mauvaise intention. Distinction qu'il peut être intéressant de confirmer, mais qui semble en effet faite par les VISOV.]	28/11/2018 09:43	VISOV (LMO) : "j'injecte 4 d'affilé dont un sur la rumeur", en parlant d'input RSN, donc soit du tweet ici ou des commentaires dans la salle Whatsapp.	28/11/2018 09:38	pasquini demande au COS s'ils avaient des infos sur Belmondo et le cos a répondu "non vous pouvez contredire" Pasquini décide d'appeler directement la comm' de la prefecture pour l'affaire Belmondo. 'il devait pas jouer, mais il va jouer'	28/11/2018 09:56	Rumeur belmondo est mort dans l'inondation d'après les VISOV. Demande de confirmation sur WA de cette info par les VISOV, ça a l'air d'être une rumeur	28/11/2018 09:40		
	LMO et FAPA s'étonnent que Loic soit au taquet sur WA pour demander à vérifier la rumeur sur Belmondo	28/11/2018 09:44					Rumeur de belmondo mort retwitté également (Correspond sans doute à la propagation de la rumeur)	28/11/2018 09:41		
	Sur WA, indication par la cellule MSGU qu'ils ne traitent pas l'information pour Belmondo car pas + d'infos.	28/11/2018 10:01					"On ne parle pas de belmondo"	28/11/2018 09:59		
							Msg sur WA aux VISOV "Pas de réaction sur belmondo de notre part"	28/11/2018 10:02		
							Officier "Ca va ça se passe bien ?" -"On a toujours la rumeur sur belmondo et les gens descendent dans les caves". "Quelle drôle d'idée, pourquoi est-ce qu'ils descendent dans le caves, ils devraient monter au grenier "	28/11/2018 10:14		

Figure 5. Belmondo case and related observation lines

Figure 5 gives a compilation of the observation lines mentioning the "Belmondo's death case". In the table, column 1 gives the studied social media input, and the 6 other columns give the observation lines related to this input for each observer. Each observation line is stamped with the date and time. Thus, one can follow, approximately, the reaction time for considering the information, and how the information has been dealt with. Here only 2 minutes separate the input by the VISOV (ANIMATION 2; 9:38 am) from its observable consideration by the MSGU team (MSGU; 9:40 am). In that case, it is because no other source had confirmed or given more detail about this information that the decision is made to not react (CODIS; 9:56 am). The MSGU team lets the VISOV (played by the organizational team) know this decision (ANIMATION 1; 10:01). As no field action is undertaken, nothing appears in column COS. As this information was not foreseen by the phone calls scenario, nothing appears in column CRAU.

The same processing could be done for all the simulated tweets and for which the observations lines are precise enough (here is one of the drawbacks of the method). According to the first exploration of the data, the observation grid enables to follow the "checks and balances" process used by the players to validate or trust a social media information. A useful concept from the pragmatic sociology can be heuristic here: the "credibility trials" (a specific case of "trials", the explained concept in section 2). This concept is useful to describe the process and the steps to which an information is submitted to in order to be declared accurate. For instance, it was used to explain how and when a whistle-blower would be found reliable (Chateauraynaud and Torny 1999). It was also used to describe the checks a call taker makes before considering a phone call as serious (Boullier 1994). More recently, it was used to describe the steps a plaintiff (complaining for police violence) must face in order to be authorized to sue a policeman (Moreau de Bellaing 2016). At each step of the "credibility trials", the information, the whistle-blower, the plaintiff can be declared not reliable. The general principle is that there is a presumption of un-credibility: each trial must be positive to clear this presumption.

Thanks to the observation made at the Call Centre and the crisis room we can compare the processing of social media information and emergency phone calls information. One strong hypothesis suggested by the data so far is that the "credibility trials" are more complicated for social media information than for emergency calls information. Several facts tend to confirm this hypothesis.

Firstly, it seems that the MSGU/SMEM team (located inside the crisis room) only considered a social media information if it was also supported by a less questionable information source. For example, the same information (children stuck in a bus) reached to the crisis room both by an emergency phone call and a tweet. Nevertheless, the tweet came with a photo of a minibus, and not a bus, whereas the phone call mentioned a bus. For a while, credibility was given to the phone call, and the crisis room advised the firefighters to look for a bus first, and in a second time for a minibus (at that moment in the crisis room, whether the tweet and the phone call referred to the same event but with different descriptions of it, or if they respectively matched a specific event was not clear). Actually, the scenario talked about a minibus: the tweet was given credit only when another phone call clearly announced that it was a bus and not a minibus.

Secondly, in the organization room, people in charge of pushing tweets tended to "worsen" some information in order to prevent the MSGU/SMEM team from ignoring them. Another strategy was to post them a second time, to put some pressure on the MSGU/SMEM team. This was the case, for instance, for an information saying that water was entering some buildings cellars. According to the scenario, this information should have come from an

emergency phone call and from a tweet. But as the organization team had the feeling that social information was not considered enough, they decided to cancel the phone call and to only give this information through Twitter. They also decided to add a new information in order to make the firefighters react: the fact that some people were on site (and so hypothetically in danger).

Finally, observations of the firefighters' field activity tend also to support the hypothesis of stronger "credibility trials" for social media information. If the Emergency Operations Commander was to receive any information coming from the social media, he systematically sent a reconnaissance mission and not a direct mission (i.e. with specific means). The commander used another mission to check whether the social media information was correct before dedicating specifics resources to this information. This was the case for the flood cellars. Firefighters on ground explained that, during the simulation, the information they were given was only that "there were people on site". But whether they were in danger was not clearly said. And as there was already some firefighters in the area (for another case), the commander asked them to check the situation on their way back.

Thus, these initial elements enable to put forward the hypothesis of stronger "credibility trials" for social media information. More in-depth analysis must be done, notably with a systematic comparison with the processing of other information sources.

…reinforced by institutional and professional dynamics

Some institutional and professional dynamics, proper to this Firefighters' department, reinforced the moments of organizational hesitation or uncertainty due to the questionable statute of social media information. One can formulate the hypothesis that those more general dynamics could have limited the propensity of the players to take into account an information coming from social media. Two examples can be given here.

First, the organization team, during the simulation, was surprised because they thought – during the exercise – that social media information was not considered at all or very little by the MSGU/SMEM team. Apparently, this perception would come from the delay between a field intervention (once an information is checked) and its "creation" into the SDIS' information system (which was the only way, theoretically, for the organization team to know what action had been taken in response to an information). Actually, firefighters on the field explained that this delay was due to practical difficulties and not to the undervaluing of social media. They gave the example (during the debriefing) about a case with two boys on a zodiac boat: it was the social media input which have triggered a field intervention (not the re-posting of the information by the animation team), even if this intervention was computationally "created" later. Apparently, this delay is not due to the questionable statute of the social media. Indeed, it was also the case for other missions. It is a problem well known by the SDIS' members: operational staff gives priority to emergency actions and not to the "creation" of these actions into the information system.

The second example is also related to this "acknowledgment" issue. The acknowledgement is the action of confirming that an information is taken into account, well received. It concerned the communication between VISOV and the MSGU/SMEM team. The VISOV representative noticed that it was not possible for him to know whether the information he had gave to the MSGU team was really received (even if this information was not meant to trigger any action). This could explain some re-postings of an information which could eventually disturb the MSGU team. During the debriefing, the firefighters and the VISOV agreed that this "acknowledgment" could be a good practice.

DISCUSSION

Is a crisis management exercise a sociological experiment?

At this stage of the study, a temporary conclusion can be made about the consideration of social media information. In this French firefighters' department, a questionable statute is given to information coming from social media. Even if firefighters are quite aware about the benefits and the need to consider this new information source, they are reluctant to fully trust it. This lack of trust seems strongly determined by the variable quality of social media information (Kropczynski et al. 2018; Tapia et al. 2013). For now, these emergency managers are on an ongoing process of acculturation to social media. As Kaufhold and Reuter observed at the Frankfurt Fire Departement, "progressive organizational culture is required to enable a successful integration of social media" (Kaufhold and Reuter 2017, 607).

Nevertheless, one need to be careful about these temporary results. This was a crisis management exercise and if an observation was to be made during a real crisis, things would have probably happened in a different way. Maybe the consideration given to social media information would have been less important.

This leads to question the value of crisis management exercise for research purposes. Simulation cannot be a replication of the social reality. It cannot be easily a social laboratory as too many variables are excluded (Guggenheim 2012). Organizing a simulation specifically to make observable what the researcher would like to observe can lead to the misinterpretation of the data. This is not to say that what happens during an exercise is not real and senseless (both for researchers and professionals). As Katz showed, it is not because a situation is altered or even triggered by the researcher or the experiment that what is observed is not real or research relevant (Katz 1983). However, one needs to be careful, as researcher, to not over-interpret some results as many variables are flattened during an exercise. The MACIV research project has two forthcoming exercises to run. It could be a good opportunity to work more on the epistemological implications of crisis management exercise as research tool (and to propose some guidelines for further research).

Social Media: a new form of capital/resource for emergency professionals?

One could also learn more about the way that the consideration of social media information as new resource is going to re-shape (or not) the role of every entity of the emergency management. When one looks at the Var's SDIS, for instance, one can observe that there is a valuation of some members with what one may call a lower "firefighter capital/resources" but a stronger "social media capital/resources". Indeed, the MSGU/SMEM team mainly consists of firefighters situated at a low rank of the symbolic firefighter hierarchy. Their social media skills gave them the opportunity to be given a specific role (social media analyst) in the organization. As the sociology of organization shows, the adoption of a new technology or tool within an organization is the opportunity for some actors to gain prestige or to value under-estimated skills (Chiapello and Gilbert 2013).

More generally, into the emergency management field there is a new type of actor – VOST/VISOV – getting power by being in an intermediary position between citizens and institutional and professional actors. Like at the Frankfurt Fire Department, at the Var's firefighters' department, "spontaneous volunteers and social media communities are valued as important stakeholders in overcoming emergencies or large-scale-disasters, but due to limited resources, it is impossible to moderate them all" (Kaufhold and Reuter 2017, 609). Moreover, "additional research is required concerning the optimal implementation and evaluation of VOST (609). Can we describe them as a "sequential marginal actor" (Crozier and Friedberg 1977), a concept used to explain the power a person can get from belonging to two environments (here emergency field and social media) that usually do not meet ? Beyond the potential gain of power for this type of actor (individually or as a group), the effects of this in-between position are to be studied. Do the VOST/VISOV act as an "intermediary" or "mediator" actor as defined in the Actor Network Theory (Latour 2005) ? According to the ANT, an intermediary actor or entity does not alter what is exchanged between two entities whereas mediator do affect the exchange. Knowing whether virtual volunteers act like a simple filter – intermediary actor – or like an active filter – mediator – (and if so, what would be the nature and the effect of this alteration?) is a stimulating research track.

Thus, more investigations could be undertaken on to whom social media and citizen-generated content are beneficial. Because the integration of social media information within the emergency management does not simply and automatically lead to citizens empowerment. Like in every process or system where an agency is given to citizens, this agency is driven by professional or semi-professional actors who can use it as a new resource.

CONCLUSION

This paper sets out the methodology and the temporary results of an ongoing research project. It discusses the benefits and limits to use an emergency crisis exercise for research purposes. The described observation protocol, and the presented coding could be replicate to survey further exercises and simulations. Some possible processing of the observation data has been exposed and further visualizations of the data (e. g., by a time line or by social media inputs) are still in progress.

One the first analytical results tackles the way Var's firefighters consider (or not) social media information. For now, social media seem to be regarded as questionable because they do not easily fit into the organizational routine. The comparison between emergency phone calls processing and the social media processing should be pursued.

On the analytical level, the paper tries to use sociological concepts (from the Actor Network Theory and from sociology of organization) to describe and explain some results. The concept of "credibility trials" was used to describe the specific processing of social media information: as observed actors confer a questionable statute to social media, the "credibility trials" are more important than for the other information sources.

On the practical level, the location of the MSGU/SMEM team in the firefighter's crisis room and not in the Call Centre is an issue. This organizational feature contributes to distinguish social media information from more classical information sources. This spatial layout reinforces the cognitive distinction between social media and other information sources. The involved firefighters explained this choice by the double role they give to the MSGU/SMEM team : to report some emergency events (just like emergency phone calls) and to improve the situation awareness of the crisis room (Endsley 1995). Clearly, the situation awareness is for now favoured. Exercises 2 and 3 of the MACIV project (with other institutional partners) might give some useful comparison and feedbacks on that matter.

ACKNOWLEDGMENTS

This study is part of the MACIV project, funded by the French Research Agency. I thank all the players and the organizers of the crisis management exercise. The Var Firefighters' department was very helpful and a driving force to this stage of the research project. I also thank the other observers very much for the data collection: Robin Batard, Sandrine Bubendorff, Julien Coche, Aurélie Montarnal, Caroline Rizza. Finally, I would like to thank the three reviewers for their constructive comments.

REFERENCES

Akrich, M., Callon, M., and Latour, B. (1988). "A quoi tient le succès des innovations ? 1 : L'art de l'intéressement." *Annales des Mines - Gérer et comprendre*, (11), 4–17.

Aupetit, M., and Imran, M. (2017). "Interactive Monitoring of Critical Situational Information on Social Media." Albi, France, 673–683.

Azzouz, M. (2012). "Les effets de l'acculturation à internet et aux technologies mobiles : le cas d'un établissement bancaire français." *E-Journal od Digital Entreprise UQAM / UCA*, (34), http://www.scientifics.fr/ejde/html/1776-2960%20R342.htm.

Benaben, F., Mauras, M., Trupti, S., and Salatge, N. (2016). "A Metamodel for Knowledge Management in Crisis Management." *49th Hawaii International Conference on System Sciences*, Koloa, HI, USA.

Boltanski, L. (2011). *On critique: A sociology of emancipation*. Polity, Cambridge.

Borraz, O. (2007). "Risk and Public Problems." *Journal of Risk Research*, 10(7), 941–957.

Borraz, O., Gilbert, C., and Joly, P.-B. (2007). "Risk Studies: The French Contribution." *Journal of Risk Research*, 10(7), 899–904.

Boullier, D. (1994). *Les dispositifs de sécurité dans les transports urbains. Etude socio-ergonomique*. Réseau 2000, RATP / Prospective, 153.

Castillo, C., Mendoza, M., and Poblete, B. (2011). "Information credibility on twitter." *Proceedings of the 20th international conference on World wide web - WWW '11*, ACM Press, Hyderabad, India, 675–684.

Chateauraynaud, F., and Torny, D. (1999). *Les sombres précurseurs. Une sociologie pragmatique de l'alerte et du risque*. EHESS, Paris.

Chiapello, È., and Gilbert, P. (2013). *Sociologie des outils de gestion*. La Découverte, Paris.

Crozier, M., and Friedberg, E. (1977). *L'acteur et le système*. Le Seuil, Paris.

Denis, L. A. S., and Hughes, A. L. (2012). "Trial by Fire: The Deployment of Trusted Digital Volunteers in the 2011 Shadow Lake Fire." *Proceedings of the 9th International ISCRAM Conference – Vancouver, Canada, April 2012*, L. Rothkrantz, J. Ristvej and Z. Franco, eds, Vancouver, Canada, 10.

Dodier, N. (2005). "L'espace et le mouvement du sens critique." *Annales. Histoire, Sciences Sociales*, 1(60ème année), 7–31.

Elbanna, A., Bunker, D., Levine, L., and Sleigh, A. (2019). "Emergency management in the changing world of social media: Framing the research agenda with the stakeholders through engaged scholarship." *International Journal of Information Management*, 47, 112–120.

Endsley, M. R. (1995). "Toward a Theory of Situation Awareness in Dynamic Systems." *Human Factors*, 37(1), 32–64.

Giddens, A. (1990). *The consequences of modernity*. Polity Press, Cambridge.

Grant, T. J., Geugies, F. L. E., and Jongejan, P. A. (2013). "Social Media in Command & Control: A proof-of-principle experiment." *Proceedings of the 10th International ISCRAM Conference*, Baden-Baden, Germany.

Grant, T., and Jongejan, P. (2011). "A Refined Framework for Crisis Management Communication via Social Media." *Proceedings of the 8th annual work conference of the Netherlands Institute of Government (NIG 2011)*, Rotterdam, The Netherlands.

Guggenheim, M. (2012). "Laboratizing and de-laboratizing the world: changing sociological concepts for places of knowledge production." *History of the Human Sciences*, 25(1), 99–118.

Hiltz, S. R., Kushma, J., and Plotnick, L. (2014). "Use of Social Media by U.S. Public Sector Emergency Managers: Barriers and Wish Lists." *Proceedings of the 11th International ISCRAM Conference*, Pennsylvania, USA, 602–611.

Katz, J. (1983). "A Theory of Qualitative Methodology : The Social System of Analytic Fieldwork." *Contemporary Field Research*, R. Emerson, ed., Little-Brown, Boston, 127–148.

Kaufhold, M. A., and Reuter, C. (2017). "The Impact of Social Media in Emergencies: A Case Study with the Fire Department of Frankfurt." *ISCRAM 2017 Conference Proceedings-14th International Conference on Information Systems for Crisis Response and Management. Brussels, Belgium: ISCRAM*, 603–612.

Kropczynski, J., Coche, J., Obeysekare, E., Bénaben, F., Grace, R., Halse, S., Montarnal, A., and Tapia, A. (2018). "Identifying Actionable Information on Social Media for Emergency Dispatch." 11.

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford university press, Oxford.

Mendoza, M., Poblete, B., and Castillo, C. (2010). "Twitter under crisis: can we trust what we RT?" *Proceedings of the First Workshop on Social Media Analytics - SOMA '10*, ACM Press, Washington D.C., District of Columbia, 71–79.

Moreau de Bellaing, C. (2016). *Force publique. Une sociologie de l'institution policière*. Etudes sociologiques, Economica, Paris.

November, V., and Créton-Cazanave, L. (2017). *EU Sequana - La gestion de crise à l'épreuve de l'exercice*. La Documentation Française, Paris.

Reuter, C., Ludwig, T., Kaufhol, and Spielhofer, T. (2016). "Emergency services′ attitudes towards social media: A quantitative and qualitative survey across Europe." *International Journal of Human-Computer Studies*, 95, 96–111.

Reuter, C., Marx, A., and Pipek, V. (2011). "Social Software as an Infrastructure for Crisis Management - a Case Study About Current Practice and Potential Usage." *Proceedings of the 8th International ISCRAM Conference – Lisbon, Portugal, May 2011*, Lisbon, 10.

Rizza, C., and Pereira, Â. G. (2014). "Building a resilient community through social network: ethical considerations about the 2011 Genoa floods." *Proceedings of the 11th International ISCRAM Conference*, Pennsylvania, USA, 294–298.

Rizza, C., Pereira, Â. G., and Curvelo, P. (2014). "'Do-it-Yourself Justice': Considerations of Social Media use in a Crisis Situation: The Case of the 2011 Vancouver Riots." *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)*, 6(4), 42–59.

San, Y., Iii, W., and Thorkildsen, Z. (2013). *Social Media in the Emergency Management Field : 2012 Survey Results*. National Emergency Management Association.

Starbird, K., and Stamberger, J. (2010). "Tweak the Tweet: Leveraging Microblogging Proliferation with a Prescriptive Syntax to Support Citizen Reporting." *Proceedings of the 7th International ISCRAM Conference – Seattle, USA, May 2010*, Seattle, USA, 7.

Tapia, A. H., Bajpai, K., Jansen, J., Yen, J., and Giles, L. (2011). "Seeking the Trustworthy Tweet: Can Microblogged Data Fit the Information Needs of Disaster Response and Humanitarian Relief Organizations." Lisbon, Portugal, 10.

Tapia, A. H., Moore, K. A., and Johnson, N. J. (2013). "Beyond the Trustworthy Tweet: A Deeper Understanding of Microblogged Data Use by Disaster Response and Humanitarian Relief Organizations." *Proceedings of the 10th International ISCRAM Conference*, Baden-Baden, Germany.

Vieweg, S., Hughes, A. L., Starbird, K., and Palen, L. (2010). "Microblogging during two natural hazards events: what twitter may contribute to situational awareness." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Atlanta, Georgia, USA, 1079–1088.

Vieweg, S., Palen, L., Liu, S. B., Hughes, A. L., and Sutton, J. (2008). "Collective Intelligence in Disaster: An

Examination of the Phenomenon in the Aftermath of the 2007 Virginia Tech Shootings." *Proceedings of the 5th International ISCRAM Conference*, Washington, DC, USA.

On Liquid Ground: Contesting facts and responsibilities on Weibo during the Shouguang Flood

Lixiong Chen
Department of Sociology
Lancaster University
c.lixiong@lancaster.ac.uk

Monika Buscher
Department of Sociology
Lancaster University
m.buscher@lancaster.ac.uk

Yang Hu
Department of Sociology
Lancaster University
yang.hu@lancaster.ac.uk

ABSTRACT

As one of the most well-known social media platforms in China, Weibo provides an online public sphere. During the 2018 Shouguang flood, many people who were affected converged on the platform to discuss the disaster. The government – the highest emergency management authority – was accused of using censorship and other measures to suppress the coverage of the disaster. Based on an analysis of 34 qualitative interviews with Weibo users, of which nine directly address the Shouguang floods, this paper examines how three major actors contested facts and responsibilities during the disaster. Focusing on the state-censored, market-moderated social media context in China, our ongoing study provides new insights into a universal challenge of managing diverging interpretations and expectations in risk communication. We show that the establishing and framing of facts is inherently ethical and political. Time, time-space compression, liability and scales of risk responsibility emerge as critical points of friction. We draw on theories of risk governance, public discourse, computer supported collaborative work, and media studies for analysis and to articulate avenues for design.

KEYWORDS

Chinese social media, fact contestation, transparency, authenticity, trust

INTRODUCTION

> *My parents are farmers in Shouguang, their farmland was flooded, … the crops yielded no harvest, their hard work this year has been wasted. In the two or three days after the flood, some villages, such as my parents' village, did not receive relief assistance and the serious situation was not reported on state media. … My parents do not use Weibo, so I had to send a weibo[1] to … let more people know the real situation in the disaster area, with a hope that people can donate rescue resources. My post was pushed on the trending list, I received a lot of emotional support, and some people also helped me forward the weibo to underscore the severity of the disaster. However, my post was quickly taken down. I wanted to access some disaster response information from the government Weibo [account], but I didn't see any information. I felt depressed and very helpless.'*

This story was told by Binqi (pseudonym), whose family were affected by the flood. Binqi was not alone, as many Weibo users posted information about the disaster on the platform. Their accounts differed from facts posted by the official Shandong provincial government Weibo account, and some of their posts were removed.

Our investigation takes the fact of conflicting accounts as its phenomenon. We are not on an investigative

[1] Sending a weibo is similar to sending a tweet.

mission to 'reveal' what was censored, but refer to literature on risk governance and urban environmental politics where the framing of disaster risk and disasters like Bhopal has been shown to be a social, political, and ethical process where capacities to contest facts are subject to power struggles (Jasanoff 2003, Fortun 2011, Swyngedouw 2015). There is no one truth about any disaster and our interest lies in the practices and 'infrastructures' for contestation that information systems can provide. Some are more suited to afford diverse information ecologies and democratic contestation than others (Jasanoff, 2003, Turner, Bowker, Gasser, and Zacklad, 2006; Baker and Bowker 2007; Karasti, Baker and Millerand, 2010). A deeper understanding of practices of contesting facts and responsibilities in disaster risk management can inform the design of information systems or infrastructures that can help the diverse parties involved to bring different perspectives into dialogue and develop a more democratic framing of risks, responsibilities and 'response-abilities'.

Sina Weibo is similar to Twitter in its design (Ramzy, 2011). As one of the most well-known social media platforms in China, it is used widely in emergency management by both the Chinese government and the public. Its features allow for the rapid spread of information. Therefore, Weibo provides a key platform for disaster relief and communication between the government and the public (Rigby, 2008; Ma, Zhang and Liu, 2014). The emergence and widespread adoption of Weibo also helped create an online public sphere (Xu, 2012), which enables civilians to debate social issues such as disasters by generating and posting evidence, examining and debating different versions of facts.

This paper draws on 34 qualitative interviews with people affected by disasters, of which nine directly discuss the Shouguang flood. Shouguang, an area famous for its fruit and vegetable produce in Shandong province, was hit by a serious flood from the Mi river between August 19 to 21, 2018. The flood caused thirteen deaths, three missing people, and an economic loss of 9.2 billion RMB (1.05 billion GBP), making it the worst flood Shouguang has seen since 1974 (Sina News, 2018). In this paper, we identify three major parties who constructed and contested facts around the disaster on Weibo:

(1) Official fact providers: The local Shandong government, the central government of China, disaster management agencies;

(2) Informal online fact providers: Weibo users who describe themselves as victims or who had family and friends affected by the disaster;

(3) Online onlookers: Weibo users who were interested in the Shouguang flood, but not directly or indirectly affected by the disaster. They participated by sending weibos, or commenting on posts.

A grounded theory analysis of the interviews has allowed us to draw out key practices of contesting facts. Asking 'what is the process of fact contestation of the public when a government version of disaster report is different from the public version?' and 'what is the impact of this process on future disaster response actions?', we aim to enable a deeper understanding of these practices and dimensions, supported by a discussion that draws on literature from risk governance, public discourse, computer supported collaborative work, and media studies. The aim is to inform the design of better disaster risk management sense-making practices and tools.

We found that the temporality of information release, the time-place nexus in witnessing and mediating the unfolding disaster, the liability and scales of responsibility are points of friction, which are contested by different actors on the Weibo platform. Overall, the paper not only demonstrates the process of fact contestation on Sina Weibo, it also suggests that the divergent constructions of facts could be a resource for better collective risk governance to promote a better cooperation between different disaster responders in the future.

BACKGROUND: THE RISE OF CHINESE SOCIAL MEDIA AS A STATE-CENSORED AND MARKET-BROKERED PUBLIC SPHERE IN DISASTERS

Thanks to the evolution of digital technologies, the public sphere has expanded into online space. This is a global phenomenon, and one that is highly contested. From Egypt's shut-down of the Internet during the Arab spring to concerns about voter manipulation during the 2016 US elections and UK Brexit Referendum, and debates about Internet control in Russia, governments, public safety services, commercial platform operators, regulators and citizens struggle over how common information spaces should be inhabited and governed (Millian, 2011; Bright, 2017; Ball, 2019). The online public sphere is a space in which a wide range of voices can be expressed due to the 'low barrier of entry' and interactivity (Edgerly, Vraga, Fung, Moon, and Yoo, 2010). In controlled information environments such as China, positive effects of social media on reducing state control of information and encouraging the development of civic engagement have been identified (Herold and Marolt, 2011; Tufekci and Wilson, 2012; Kaur, 2015), and a semi-managed online public sphere for Chinese citizens is emerging. However, the transformations and effects for crisis response and management are complex.

Writing in a Western European context, Habermas (1989, p.52) defined the public sphere as a 'society engaged

in critical public debate', which lies between the Private Realm (the personal domain) and the Sphere of Public Authority (the state, the police, the ruling classes). In this realm, private individuals assemble as a public body, and public opinion forms. In Habermas' theory, freedom of assembly and association, and freedom to express and publish their opinions, allows citizens to behave as a public body to discuss matters of general interest. In democratic societies, access to this domain is 'open in principle to all citizens' (Habermas, 1989, p.231).

Social media can be seen to open up an independent space online for individuals to engage in political communications (e.g. Yang, 2003). However, researchers are also observing opposing trends, such as the foreclosure of political debate through 'communicative capitalism' where online participants merely vent observations or views with no true dialogue (Dean, 2005). This interplay of contradictory forces also applies to China. Weibo is increasingly used by individuals 'as a new battlefield where the state and social groups fight for power and interest' (Wu, 2015, p.204). Following the 2011 train crash in China, Weibo users expressed concerns that the government had attempted to conceal evidence instead of supporting the rescue (Ma, Yuan, Zhang and Liu, 2012). In the 2015 Tianjin explosion, Weibo users believed that the Tianjin government shirked its responsibility and concealed the cause of the explosion and the accountability of local government. Weibo users succeeded in attracting the public's attention, which forced the government to respond to these perceptions of disaster response. By facilitating political debate and organising collective civic activities, the online public sphere that has emerged on Weibo enables the 'articulation of social problems and has shown some potential to play a supervisory role in Chinese politics' (Yang, 2003, p.474).

However, the model of the public sphere in Chinese society differs from Habermas' theory (Tong, 2015; Rauchfleisch and Schäfer, 2015). A number of factors undermine the applicability of classic public sphere theory in the Chinese context. The most significant factor is that the Chinese public sphere is not free from government control, as the Chinese government has devised a series of supervision and censorship mechanisms that restrict the communication of information and speech in certain topic areas by deleting weibos posted by individual users and by removing weibo threads from the Trending List.

Yet, although the government regulates, manages and limits communications, it also has to maintain 'the stability of the online public mood' (Li, 2010). The public can engage in debates online, but the topics they can discuss and the opinions they can express are severely restricted as a result of government censorship. At the same time, the social media public has the power to influence public opinion. This has led to a semi-managed online public sphere, which is a state-censored, market-moderated social media environment. In this paper we ask 'How is this organized and experienced?' and 'What are consequences and opportunities for disaster risk management?'. We proceed with a short discussion of our methodology and then turn to a presentation of qualitative data. From this, we draw out and discuss key themes and implications for the design of information systems for crisis response and management.

METHODS

The analysis is built on a case study of the 2018 Shouguang flood, which is part of a bigger ongoing study on the transformation of disaster communication in China via social media, focusing on Weibo. Qualitative methods were used to enable a deeper understanding of practices of disaster communications on Weibo. For the bigger project, 235 Weibo users were selected as potential candidates for interviews, the main criteria of recruitment being that different types of user candidates sent weibos during Chinese natural disasters to ensure their use of Weibo in a disaster. In addition, the type of Weibo user is further divided the sample into several subgroups. Weibo requires users to provide phone number, birth date, gender and location upon registration, and it enforces a hierarchy of 'unverified' and 'verified' users. The most common categories of 'verified users' are:

- Individual users
    - 'Red Verified Users' who have posted >20 articles/videos and earn >1,000,000 reads per month
    - 'Yellow Verified Users' who have >10,000 reads per month and support 2 Verified users
- Organisations who pay a fee or use the business license as the organisational identification, such as news organisations and government sectors.

For the ongoing research project, so far 37 interviews were conducted. These participants have been recruited through Sina Weibo private message (22) and snowball sampling (15). Three participants withdrew from the interview. Our research ethics means that they were not requested to provide a reason. The research overall is thus based on 34 interviews (5 Blue, 5 Yellow Verified Users, 24 Unverified Individual Users).

All interviews were conducted between October and December 2018. Before the interview, background information about participants was collected, including gender, age, employment status, disaster concerns and

reasons for concern. The 34 participants' reasons for engaging on Weibo during disasters fall into four categories: (1) interest in the disaster, including disputes over causes and the response of the government; (2) the affected area is the respondents' hometown; (3) personal exposure to the disaster; (4) engagement in rescue-related work.

Semi-structured interviews were conducted online, Questions started with an exploration of the participants' knowledge of the disaster, followed by questions about their use of Weibo, such as 1) How did you use Weibo in the disaster? 2) Why did you choose Weibo to find or send disaster information? 3) What kind of information did the government Weibos publish when you used Weibo during the disaster? 4) What kind of information on Weibo do you think is appropriate in a natural disaster? How do you define 'appropriate'? 5) Could you explain the advantages and disadvantages of Weibo? All interviews were conducted in Chinese, transcribed and translated. We have anonymised all data.

Nine of the interviewees directly discussed encountering the issue of fact contestation as they participated in communications around the Shouguang floods. Therefore, in this article, we focus on the interviews with these nine respondents. In exploring how they made sense of fact contestation, an open-ended interview design was used to allow the respondents the space to construct their narratives. For example, the interviews started with the question, "could you please describe what you know about the disaster and how you got to know about it?". If respondents referred to the governmental report, they were then asked about whether the governmental report concurred with the information they received from Weibo. If the respondents mentioned that they had posted about the disaster online, they were asked the questions, 'What did you post? Why on Sina Weibo?' Simple and short questions were used to enable the respondents to clearly and fully understand the questions.

DATA ANALYSIS

Table 1 below provides an overview of the respondents' role, behaviour, and uses of Weibo. After this, we discuss key findings.

Table 1. List of interviewees

Participant	Age	Gender	Occupation	Location	Role	Activities	Sina Weibo Uses
Yi	27	Female	New Media Editor	Nanjing, Jiangsu	Onlooker	Accessed information; Forwarded	Sharing disaster information; Calling for relief efforts; Expressing emotions
Penna	26	Male	Student	Chengdu, Sichuan	Onlooker	Accessed information; Forwarded	Sharing disaster information; Calling for relief efforts; Discussing causes and relief power
Stone	24	Female	Student	Osaka, Japan	Onlooker	Accessed information; Forwarded	Sharing disaster information; Calling for relief efforts; Expressing emotions
Weipin	25	Female	Student	Shouguang, Shandong	Online fact provider	Accessed information; Sent weibos; Forwarded	Reporting the disaster information; Sending rescue request; Calling for relief efforts; Discussing causes and relief power; Sharing disaster information
Binqi	26	Female	Lawyer Assistant	Nanjing, Jiangsu	Online fact provider	Accessed information; Sent weibos;	Reporting the disaster information; Sending rescue request; Calling for relief efforts;

						Forwarded	Discussing causes and relief power; Sharing disaster information
Clara	21	Female	Fashion Brand PR	Xiamen, Fujian	Onlooker	Accessed information; Forwarded	Sharing disaster information; Calling for relief efforts; Expressing emotions
Ming	19	Female	Student	Shouguang, Shandong	Online fact provider	Accessed information; Sent weibos; Forwarded	Reporting the disaster information; Sending rescue request; Calling for relief efforts; Discussing causes and relief power; Sharing disaster information
Yuhan	21	Male	Actor	Shouguang, Shandong	Online fact provider	Accessed information; Sent weibos; Forwarded	Reporting the disaster information; Calling for relief efforts; Sharing disaster information
Tian	23	Female	Student	Harbin, Heilongjiang	Onlooker	Accessed information; Forwarded	Sharing disaster information; Calling for relief efforts; Expressing emotions

KEY FINDINGS

In the age of social media, the gap of trust between the authorities and the public in China has been widening. Despite an increase in the presence of government on Weibo and the government's tightening regulation of social media platforms, Weibo still constitutes a relatively open online public sphere in which members of the public can discuss various social issues. During the Shouguang flood, government Weibo accounts and individual Weibo users' accounts — both those from the affected area and those whose families and friends were affected by the flood – diverged significantly. This led to heated contestation over the authenticity and trustworthiness of distinct versions of facts on Weibo. In this process, government Weibo accounts were perceived to be the official fact provider, while individual Weibo users with first-hand experiences of the flood either themselves or through their family members and friends assumed the role of online fact providers. As news of the flood spread, onlookers began to voice their opinions and partake in the process of fact contestation.

Multiple practices of generating and consuming 'facts' on Weibo

Platforming disaster 'facts', Weibo fulfils two major functions of social media, as identified by Ma and colleagues (2014): Weibo supports multiple practices of generating 'facts' about disasters, and it also provides an avenue for users to learn about, and moderate the 'facts', from within and outside the disaster-stricken areas.

With an aim to draw attention from emergency departments and Weibo users outside the affected areas, online fact providers such as Weipin, Bingqi, Ming and Yuhan began to post about the flood from within the flooded areas. Given the large number of active users, the online fact providers believed that the Sina Weibo would enable them to spread information in a rapid manner to reach a wide-ranging audience. To depict situations in the flood-stricken areas, the online fact providers posted textual descriptions, photos and short video clips. To justify the authenticity of such posts, geotags were used.

For example, Binqi posted about the flood on behalf of her parents who do not know how to use Weibo. Explaining why she chose to use Weibo as a platform to present her version of facts, she said, 'Sina Weibo is a very mainstream social media platform right now, for all to see, for all to search, for all to access information'. Weipin, another online fact provider, is a student who uses Weibo on a daily basis. After receiving a Weibo

notification of the flood from the local neighbourhood committee, she immediately searched 'Shouguang flood' on Weibo and participated in providing civil news coverage on the flood. As she explained why she '[relied] on Weibo to follow the latest developments of the flood', she said, 'There are so many active users on Weibo, which allows Weibo to provide more comprehensive information (than some other platforms)'. Notably, online fact providers often provided 'facts' that differed from those published by the government.

Weibo not only enabled some users to generate facts about the flood at close quarters, it also allowed other users to follow and interact with news on the flood from afar. Yuhan is a young actor, some of his followers are also actors with a large number of followers on Weibo. As a celebrity, he thought that posting about the flood on Weibo would facilitate rapid dissemination information his followers re-post the facts. As onlookers (Yi, Penna, Stone, Clara and Tian), individual Weibo users outside the affected areas considered Weibo as a readily accessible platform to obtain any latest news about the flood. Yi is a social media editor who uses Weibo for her everyday work and relies on the 'hot search' function on Weibo to access the latest news. She explained how she actively retrieved information on the Shouguang flood from Weibo:

> *I heard about the flood from my friends. Then I searched the flood on Weibo. Weibo is my daily source of information. I am used to following events on Weibo because I can get real-time information from multiple sources. In Shouguang flood, I saw a lot of Weibo posts sent by people from the flood-stricken areas. The posts showed the dangerous situations in the flood zone. I also saw some videos posted by Yellow V Weibo users providing descriptive accounts of the disasters, such as interviews with local farmers from the flooded areas.*

The use of Weibo in disasters is particularly prevalent among the younger generation. Tian, a 23-year-old student, indicated that almost all her peers relied on Weibo to consume news. She further noted that the interactive nature and diversified sources of information make Weibo a particularly attractive way of accessing the news. Tian compared Weibo with traditional media such as TV. She went on to criticise the latter as a slow and inefficient means to disseminate news. '*I use Sina Weibo frequently. Browsing Weibo has become an everyday leisure activity for me. I came across (the news of) the flood while I was browsing on Weibo. Then I kept searching and following updates on the flood*', Tian said. And, as a Chinese student studying in Japan, Stone noted that Weibo helps break down geographic barriers for her to learn about domestic news such as the Shouguang flood in China. Onlookers such as Clara and Tian noted that the information from Weibo raised the public awareness of the flood, which helped attract disaster relief resources and donations.

What are the contested facts?

Contestation of facts about the Shouguang flood centred on three issues, namely the causes and severity of the flood and the government's delivery of relief resources.

Description of the cause of the Shouguang floods and the situation

On August 20th, the CCTV released its official news of the Shouguang flood. Reporting from upper Mi river, the journalist stated that the flood situation was not serious. According to the news, the flood did not affect the villages downstream, and the local government had already dispatched rescue teams to the affected areas (CCTV, 2018). On August 23rd, the Weifang city government held the first flood control and relief news conference. Attributing the cause of flood to heavy rainfall, the spokesperson vaguely mentioned that Shouguang had been hit by a flood:

> *Under the influence of Typhoon Rumbia, heavy rain swept Weifang. Some cities and towns have been flooded…The heavy rainfall led to a rapid rise in the water level at three reservoirs. To prevent the dam from collapsing and for the safety of nearly one million people downstream, the municipal government released the floodwater downstream. However, Shouguang was still seriously flooded' (Global Times, 2018).*

At the news conference, no detail on the situation in Shouguang was released. The conference was covered by several news agencies on Sina Weibo, such as @Sina News and @Beijing News.

The CCTV news report was vehemently contested by Weibo users (CCTV, 2018). The online fact providers initially used Weibo to vent their anger at the journalist who was criticised for having misled the public to believe that the situation in Shouguang was not serious and that the area had received adequate rescue resources from the government.

Individual Weibo users such as Ming and Binqi provided a version of facts that is vastly different from the one included in CCTV report and the government's official press release. Weibo users believed that the cause of the

Shouguang flood was a complicated combination of human errors and natural causes.

Ming is a student who lived in a small town near Shouguang. As her town lies at the far side of Shouguang away from the Mi river, the town was not seriously affected by the flood. She saw the CCTV report on Weibo and noticed that the report failed to reflect the real situation based on what she had seen, what her relatives had told her, as well as some other information she had obtained on Sina Weibo. She recalled that 'the reporter said that the upstream flood had no impact on the downstream, we Shouguang people were outraged because the damage was really serious!'

Although a Shouguang local, Binqi was away from Shouguang during the flood. Although Bingqi was not able to participate in the disaster-relief herself, she contributed by drawing people's attention to the flood on Weibo. Dissatisfied with the CCTV report, she posted on Weibo: 'The CCTV misled the public by reporting that the upstream reservoir flood did not cause serious damages to the downstream areas. Due to the absence of rescue forces, villagers suffered heavy losses.' Binqi further explained how she first learnt about the 'facts' from her families and friends living in Shouguang:

> *Shouguang is my hometown. Although I don't live in Shouguang now, my parents and friends still live there. They told me that it rained heavily for several days in a row before the flood, which caused the upstream Qingzhou reservoir to overflow. This forced the local authority to discharge flood water from the reservoir, which flooded several villages on both sides of the river…The villagers suffered heavy losses. My parents' farmland was flooded. The flood swept away all crops that were about to be harvested.*

Weipin, an onlooker on Weibo, described that although the flood did not have a significant impact on her own life, she was upset to learn that such a severe disaster was not merely of a natural cause:

> *It is not just the heavy rain that caused such severe impact on Shouguang. The human error in mismanaging the upstream reservoir was also a main cause. Also, the villagers did not receive any notification from the reservoir team in time before they discharged water from the reservoir, which made the situation even worse...*

The government's rescue and relief delivery

Whether the government sent its rescue team and adequate relief resources to the flooded areas as claimed was another area of contestation on Weibo. In the news conference, the Weifang government announced that it had sent a relief team and relief goods to Shouguang. It was also explained that the Shandong party secretary had arrived in Shouguang in the evening of August 22nd, four days after the outbreak of the flood, to direct the disaster relief work.

The online fact providers accused the Shandong and central authorities of inaction. For example, Binqi and Yuhan posted on Weibo that the local firefighters and the police force in Shouguang rushed to the disaster area on the second day of the flood, which was far from sufficient. Other Weibo users, such as Ming, used the @ function to draw attention from government departments and state media outlets such as CCTV, pleading them to dispatch disaster relief and supplies. However, they did not receive any response from the official Weibo accounts at which they posted. Some other online fact providers also shared their first-hand experiences of the rescue situation on Sina Weibo. For example, Ming posted:

> *There are rescue teams in some of the worst-hit areas. However, I saw Weibo posts from many users with geotags in Shouguang saying that the disaster areas were "cordoned-off" and they were not allowed to contact the outside world. The rescue does not seem to go well either.*

As the online contestation developed further, '#Shouguang self-rescue' started to trend on Weibo and develop offline, according to Binqi. Using Weibo, local residents spontaneously self-organised to rescue people trapped in the flood and to deliver relief supplies to affected villages. Rescue teams from the provincial government only arrived in the affected areas a few days later.

Facts: Divergence and diversity

The fact contestations on Sina Weibo showcased divergence and diversity as the different actors assumed distinct social positions and responsibilities. Most government official Weibo accounts had remained silent in the first four days of the flood. Following the official news conference, facts about the flood were published not only via traditional media outlets but also via government Weibo accounts.

Shouguang natives and remote fact providers also occupied different positions as they took part in the fact contestation on Weibo. Weipin, a Shouguang native indicated that 'because this is where I live, this is my hometown, and when something like this happens, I definitely have to pay attention to it.' Some other online factor providers who did not live in Shouguang posted what they believed to be true based on reports from their friends and family members. In such cases, familial and friendship, and affective ties with intimate others played an important role in authenticating and validating the 'facts' for the remote fact providers.

Onlookers also participated in the fact contestation in diverse ways. For example, Stone defended the government departments, arguing that it is essential for the government to anticipate the public's response and consider whether any given facts may cause public panic and anger. Stone further explained that the official version of facts was necessarily constructed to maintain social stability and to mitigate negative social impacts arising from the flood. Unlike Stone, some other onlookers chose to trust online facts over government statements because they believe that the government may intend to cover up their negligence of responsibility, while others remained cautious for fear of misinformation.

In the aftermath of the disaster, many onlookers also acted upon the diverse facts in which they believe. One week after the flood, Tian accessed disaster-related information from the hashtag #Shouguang Flood. After reading about the dire disaster rescue situation, Tian donated relief supplies following the donation information posted on Weibo. She reflected that 'I didn't think about it too much, and then maybe I was just guided by the words posted by the affected people on Sina Weibo.' While some interview respondents expressed their doubts over the trustworthiness of donation appeals on Weibo, others believed that the government had already delivered sufficient rescue and relief resources.

DISCUSSION AND CONCLUSION: CONSTRUCTING FACTS, ACTORS, INTERACTIONS, INFRASTRUCTURES

Our analysis shows how the different users of Weibo construct the facts of the Shouguang floods differently. In and as part of these communicative struggles, actors, modes of interaction, infrastructures and practices of making sense of the disaster are shaped. Three key actors emerge:

(1) The Shandong Weifang/the Central government

(2) Sina Weibo users who were affected or whose families and friends were located in the affected area and who documented on the ground experiences of the Shouguang flood in near real time

(3) Sina Weibo users who participated as onlookers, who witnessed the contestation of facts, including the disappearance of posts and vented their dissatisfaction or anger, or adopted a 'wait and see' attitude.

Their experiences are shaped by many factors. Two are particularly powerful.

Firstly, the timing of information release and the temporalities of witnessing the mediation of the unfolding disaster are very different for the different actors. For government agencies, the speed of information provided by Weibo users on the ground and distributed across the country is hard to control and in arrhythmia with their necessarily slower fact-checking and paternalistic approaches to releasing information. For locally or remotely affected Sina Weibo users there is great urgency in those situation descriptions and it is difficult to understand why those in power do not provide 'adequate' immediate response. And for onlookers, the censorship and disappearance of Weibo reports is deeply unsettling. Lam (2018) describes how local members of a WeChat group who shared concerns over a potential spread of disease were arrested within 15 hours of posting their messages. This was unsettling in a different way, bringing divergent expectations on risk governance to the fore.

Secondly, the scales of responsibility are a source of friction. The government is responsible not only for managing the disaster at the local and national scale in terms of response efforts and financial long-term commitments, it must also manage public opinion. Moreover, the government is responsible for innovation and growth in regional productivity – a motivation for the engineering of the dams that are implicated in the floods. Their engineering of complex socio-technical systems increases the risk exposure in the area. At the same time as they benefit from these socio-technical systems, the local community suffer from their exposure from increased risks, they expects and are dependent on rapid emergency response and relief. Local responsibilities that may have contributed to increased exposure to risk, such as settlements and agricultural use of the river-banks are not part of the discussion on Weibo (although they do come into the slower paced debates on traditional media (see, e.g. Lam 2018).

We can use Jasanoff's concept of 'technologies of humility' to explore this challenge to design further. She argues that attempts at 'disciplining the incalculable through sophisticated forms of calculation' enact ill-advised hubris (2010: 19). To counteract it, she argues, a shift from disaster risk management to risk governance is

necessary. Jasanoff envisages public engagement as complementary to formal efforts, and designs such as Ma et al.'s joint official microblog platform to improve interactive communication with the public under a centralized system are beginning to support direct communication with the public in China (2014). But there is more to a shift to risk governance than shared platforms. Jasanoff shows that collective risk governance requires not only expert professionalism and broad-based engagement with local knowledge, but also flexible infrastructures. In Jasanoff's analysis, conflicts of interest and difficulties in the control of information are not problems that must be overcome *before* partnerships can function. Indeed, she shows that the idea that agreement requires erasure of conflict and difference is misleading. Instead, like Swyngedouw (2015), she argues that a political process of understanding risk, responsibilities for risk, and the injustices involved more fully is needed.

We therefore suggest that the construction of diverging facts is not a problem that must be eradicated, but a resource for better collective risk governance. With infrastructures that better support expression of temporal and scalar disjunctures between formal emergency response agencies and the communities they serve, better collaboration may be possible. In future work we will focus on the role played by Weibo as a platform in brokering information that is crucial to the construction of facts and trust.

The limitations of this study suggest a few important directions for future research. The interview data reported in this article is only collected from unverified individual users, which do not reflect the perspectives of verified individual users and verified organisational users. As these users have considerably large numbers of followers and occupy an influential symbolic status on Weibo, their views are often based on the social roles they play and assume on Weibo that may provide the view in the other direction. Secondly, the contributions of the nine interviewees provided the main data basis for this study, however, the data did not represent the larger Weibo user groups. We will include more types of Weibo users and samples in further research to keep diversity and quantity of data to analyse complex behaviour pattern of various perspectives in disaster response.

REFERENCES

Baker, K. S., and Bowker, G. C. (2007). Information ecology: open system environment for data, memories, and knowing. *Journal of Intelligent Information Systems*, *29*(1), 127–144.

Ball, J. (2019). Russia's plan to unplug from the internet shows cyberwar is escalating. https://www.newscientist.com/article/2194009-russias-plan-to-unplug-from-the-internet-shows-cyberwar-is-escalating/ [Accessed February 15, 2019]

Bright, S. (2017) After Trump, 'big data' firm Cambridge Analytica is now working in Kenya, BBC News, http://www.bbc.co.uk/news/blogs-trending-40792078 [Accessed 12 January 2018]

Dean, J. (2005). Communicative Capitalism: Circulation and the Foreclosure of Politics. *Cultural Politics: An International Journal*, *1*(1), 51–74.

Fortun, K. (2011). Remembering Bhopal, Re-figuring Liability. *Interventions: International Journal of Postcolonial Studies*, *2*(2), 187–198.

Edgerly, S., Vraga, E., Fung, T., Moon, T. J. and Yoo, W. H. (2010) YouTube as a public sphere: The Proposition 8 debate. https://msu.edu/~jmonberg/415/Schedule_files/Edgerly_et_al_YouTube_Public_Sphere.pdf [Accessed 19 January 2019]

Habermas, J., (1989) *The structural transformation of the public sphere: an inquiry into a category of bourgeois society,* Cambridge, Mass.: MIT Press.

Hampton, K., Rainie, L., Lu, W., Dwyer, M., Shin, I. and Purcell, K. (2014) Social Media and the Spiral of Silence. www.pewinternet.org/2014/08/26/social-media-and-the-spiral-of-silence [Accessed January 20, 2019]

Herold, D. and Marolt, P. (2011) *Online Society in China: Creating, Celebrating, and Instrumentalising the Online Carnival*. London and New York: Routledge.

Jasanoff, S. (2003). Technologies of Humility: Citizen Participation in Governing Science. *Minerva*, *41*(3), 223–244.

Jasanoff, S. (2010). Beyond Calculation: A Democratic Response to Risk. In G. Lakoff (Ed.), *Disaster and the Politics of Intervention*, 14–41. New York: Columbia University Press.

Karasti, H., Baker, K. S., & Millerand, F. (2010). Infrastructure Time: Long-term Matters in Collaborative Development. *Computer Supported Cooperative Work*, *19*(3–4), 377–415.

Kaur, K., (2015) Social media creating digital environmental publics: Case of Lynas Malaysia. *Public Relations Review*, 41(2), pp.311–314.

Lam, O. (2018). As China faces record-breaking flood levels, authorities arrest two women for spreading 'rumours' of health risks, Hong Kong Free Press HKFP, 15 September 2018.

Li, S. (2010) The Online Public Space and Popular Ethos in China. *Media Culture Society*, Vol. 32, pp 63-83.

Loader, B. D.; Mercea, D. (2011) Networking Democracy? Social media innovations and participatory politics, Information. *Communication & Society*, 14 (6): 757–769.

Ma, Y., Zhang, H., & Liu, Y. (2014). Development of a joint official microblog platform to improve interactive communication with the public under a centralized system. In S. R. Hiltz, M. S. Pfaff, L. Plotnick, & P. C. Shih (Eds.), *Proceedings of the 11th International ISCRAM Conference – University Park, Pennsylvania,* (pp. 782–786). University Park, Pennsylvania.

Milian, M. (2011). Reports say Egypt Web shutdown is coordinated, extensive. from http://edition.cnn.com/2011/TECH/web/01/28/egypt.internet.shutdown/index.html [Accessed February 15, 2019]

Ramzy, A. (2011) The brain behind China's microblog machine. *Time International*, 177(17), pp.86–86.

Rauchfleisch, A., Schäfer, M. S., (2015) Multiple public spheres of Weibo: A typology of forms and potentials of online public spheres in China. Information. *Communication & Society*, 18, 139–155.

Rigby B, (2008) *Mobilizing generation 2.0: a practical guide to using Web 2.0 technologies to recruit, organize, and engage youth*. San Francisco: Jossey-Bass.

Swyngedouw, E. (2015). Urbanization and environmental futures: Politicizing urban political ecologies. In J. (ed. . Perreault, T (ed.), Bridge, G (ed.) & McCarthy (Ed.), *Handbook of Political Ecology* (pp. 609–619). London and New York: Routledge.

Thompson, J.B., (1995) *The media and modernity: a social theory of the media*, Stanford, CA: Stanford Univeristy Press.

Tong, J., (2015) The formation of an agonistic public sphere: Emotions, the Internet and news media in China. *China Information*, 29, 333–351.

Tufekci, Z. and Wilson, C. (2012) Social Media and the Decision to Participate in Political Protest: Observations from Tahrir Square. *Journal of Communication* 62(2): 363–379.

Turner, W., Bowker, G., Gasser, L., & Zacklad, M. (2006). Information Infrastructures for Distributed Collective Practices. *Computer Supported Cooperative Work*, *15*(2–3), 93–110.

Wang, Q., (2017) The semi-structured online public sphere in China: institutional criteria and political functions. Doctoral thesis, University of East Anglia.

Wu, G. (2015). Paradoxes of China's prosperity: Political Dilemmas and Global Implications. Singapore: World Scientific Pub. Co: 204-205.

Xu, Y. (2012) Understanding Netizen Discourse in China: Formation, Genres, and Values, *China Media Research*, Vol. 8, No.1, Year 2012, pp15-24;

Yang, G. (2003) The Internet and Civil Society in China: a Preliminary Assessment, *Journal of Contemporary China*, Vol. 12, No. 36, pp453-475.

News Links:

CCTV, 2018, Typhoon Rumbia heads north to Qingzhou, Shandong: heavy rains cause flash floods damage homes, Retrieved 19 January 2019 from: http://sannong.cctv.com/2018/08/20/ARTIZKX2h2onGSgwPkWId7oR180820.shtml

Global Times, 2018, Weifang government held a flood relief news conference: Shouguang loss is serious, very sad. Retrieved January 21, 2019 from:

http://china.huanqiu.com/article/2018-08/12808595.html

Phoenix News, 2018, How many 'human-made' factors are worth asking in Shouguang flood of Shandong? Retrieved January 21, 2019 from:

http://inews.ifeng.com/59940540/news.shtml?&back

Sina News, 2018, Witness Shouguang flood fighting: The Shouguang section of Mi river has suffered its worst flooding since 1974. Retrieved January 20, 2019 from:

http://slide.sd.sina.com.cn/slide_56_52240_540825.html#p=1

Managing Risk Across Borders: ethical implications of engaging information technology for transboundary disaster collaboration

Katrina Petersen
Trilateral Research
katrina.petersen@trilateralresearch.com

ABSTRACT

Disaster management is increasingly becoming a project in managing diversity, from cross-organisational collaboration to inclusivity of voices. This is particularly prevalent when dealing with transboundary risks. New information technologies support these transboundary interactions by compiling diverse information and sources to build collaborative insight beyond what any individual organisation can know. This paper explores the ethical concerns that planners and responders face as they work with these collaborative information technologies to engage with data from other organisations, based in different data frameworks, socio-political priorities, goals, and cultures of risk. It draws on the ethical impact assessment of a cross-border collaborative crisis planning platform currently under development in the H2020 project IN-PREP to examine ethical tensions around equity, inclusion, diversity, solidarity, accountability and transparency. It discusses the consequences of such design foci for an agency's ability to notice ethical risks that emerge from working in diversity.

Keywords

Ethics, Transboundary, Responsibility, Collaboration, Information Technology

INTRODUCTION

This paper explores what ethical issues get foregrounded when borders become a focus in the design of collaborative information sharing technologies for disaster management. Specifically, it examines the tensions and concerns that emerge when actors are brought together from different cultures of risk assessment and preparedness through an interactive data framework and insight tool. As borders – national, jurisdictional, or institutional – increasingly play a role in how disaster risk information is organised and understood, questions arise around how these tools influence the ability of diverse decision-makers to address and take responsibility towards equity, inclusion, diversity, solidarity, accountability, and transparency. It proposes that articulation mechanisms to build awareness around diversity and difference, not just pathways to consensus, are necessary to build trust between responders, the tools they use, and the broader society.

By considering how having "transboundary" as a specific design goal for disaster information technology influences the attention of those using it towards ethics and the risks they assess, this paper adds to literature around digital ethics and improves understandings of how these tools lead to better societal resilience as a whole. It also offers insights, though broad and high-level, into how the design and use of these tools can be approached to develop a clearer understanding and responsibility towards how they affect the way disaster managers work, care for those they serve, and make their communities safer and stronger.

ETHICS AND TRANSBOUNDARY COLLABORATIVE DISASTER IT

Transboundary crises are considered a primary societal challenge facing Europe (Cabane and Lodge 2018). To support better cross-border cooperation and understanding for disaster planning, information technology systems

(IT) are regularly being designed and implemented. These IT systems combine data and insights to provide the broader views of a situation for more efficient coordination and more effective collaborative planning and decision-making (Pottebaum et al., 2016; Jasmontaite et al., 2015). But in combining data in ways that are mutually accessible to a broad network of actors, the IT raise ethical tensions in relation to what kind of impact on disaster management practice they make possible. These tensions go beyond semantic inconsistencies. They are accentuated by the transboundary intention of the systems and become a necessary design focal point (Bharosa et al, 2012; Panten et al., 2018). If left unaddressed, these tensions can lead to results ranging from the further marginalisation of communities to decreased solidarity between response agencies.

These IT work by collecting and translating into comparable forms different types and sources of data. These can include data from satellites, drone, CCTV, alarm sensors in buildings, and GPS worn by responders at the scenes. They can blend in historical data and the results of models, like estimated plume rates, fire spread patterns, and person movements in order to enrich situational awareness and the ability for responders to anticipate their next steps and future needs. This work with the data makes it possible for disaster responders to see across agencies and regions: they can identify resources held by different organisations, understand how their agents are positioned in the field in relation to others, and anticipate when a hazard might move beyond their capacities to know to ask for to help. They fundamentally shift the role of IT from horizon-scanning with the aim of collecting information in one place to providing analytics that enrich information to help transboundary responders detect risk, support collaborative decision-making, understand each other's strengths or resource gaps, and improve joint sense-making (Backman and Rhinard, 2018). Moreover, by structuring collaborative interactions through the sharing of data, these IT also have potential to act as forms of accountability and as professional safeguards against making bad choices (Princen et al., 2016).

However, to work, these IT must bring together overlapping, but not identical, practices of risk assessment, perspectives and voices (Muhren and van de Walle, 2010). Interests may overlap, conform or conflict, differing in how they are translated and interpreted depending on the scale of activity (Williams et al., 2019). Combined with the complexity of the existing technological ecosystems, the diverse nature of the stakeholders they support, the potential needs of communities being served, what a good result should look like becomes more difficult to assess. While in some cases these are semantic (e.g. I define vulnerability in socio-economic terms, you define it in geographic terms), more consequentially they are about translating different valences, functions and expectations of that data that (Fiore-Gartland and Neff, 2015). In doing so, the IT piece together more than just information, but different conceptions of care and of what it means to take responsibility for the well-being of others (Baker and Karasti, 2018). As these combine, ethical tensions emerge.

In the most general sense, ethics around such collaborative IT asks questions about if a tool should be used, what acceptable results are of that use, and who is responsible for such use. For some scholars, this is a debate about what satisfactory results are for society, when the tools might be wrong, or to whom are designers and users accountable to and about what (Ananny, 2016). For others it is about considering the oughts and ought nots to determine what should and should not be designed and implemented (Floridi, 2018). Identifying ethical concerns is often approached by looking at different units of analysis, including examining the technology and the rules upon which it is constructed itself, looking at the processes and ends being sought, and addressing the responsibilities and liabilities of the persons or organisations doing the actions (Brey 2012; Ananny 2016; Floridi and Taddeo 2018). These framing questions and units of ethical analysis have the potential to act as a form of societal accountability, building into the tools forms of responsibility, and integrating societal concerns into the practices with these tools (Hijmans and Raab, 2018).

However, these frames rely on a basis of commonality to start with, and do not always anticipate the collaboration or necessary ad-hoc negotiations that make working over and through a border a benefit for all involved. They approach data and the digital in a way that assumes (even if just local to a given assessment) stability and lack of contestation about what the understandings of the world are, what is a good association, and what the hopes for making a world better are (Neff et al., 2017). Putting a border as a centre of focus complicates *shoulds* and *oughts* and *betters*, as the answers to these questions and what ethical concerns they evoke are not universally normative but culturally grounded and unstable over time and scale, and thus cannot be remedied via relativism or consensus (Leonelli, 2016; Fiore-Gartland and Neff, 2015). Approach these questions in a transboundary way requires taking into account how the tools can be used by end-users in the future and their potential human rights implications for the communities on either side of the line (Stahl, 2013). Ethics becomes about elaborating and encouraging dialogue around the tensions that arise in answers to the questions about if a tool should be used and if the results of this use are acceptable.

METHODS

This work is based upon an initial ethical impact assessment for a large-scale, 3-year long, ongoing EC funded research project to design a transboundary disaster planning and training platform, IN-PREP. This project team is made up of over twenty international and interdisciplinary partners (academia, industry, emergency management practioners and trainers, SMEs) from across the EU. This project intends to create an IT structure to connect a large quantity of complex and diverse data from disparate sources, from modeling of potential hazard outcomes and impacts (e.g. smoke plumes and infrastructural damage assessment) to the local resources available and deployed by collaborating agencies. It provides data analytics and data management frameworks to help process that data and provide realistic scenarios and insights to support all actors in improving their ability to coordinate and work together.

The ethical impact assessment is a process of critical scrutiny that aims to make it easier for designers and end-users to become more aware of the features and interactions that have ethical, moral, and societal implications (Brey 2000; Wright, 2015). In the process, they each learn more about the problem domain and potential of the technology, reflecting upon the potential impacts of different design moves, diverse user practices, and the ambiguities of real-world knowledge and experience (Carroll 2000). In doing so, it contributes towards the protection of societal values and the design of effective risk management strategy (Kloza et al. 2017).

The assessment is iterative throughout the project. This paper is drawn from the first stage, produced with the project's outset before design commitments have been made. The intention of this phase of the assessment is to identify what ethical concerns might arise at various scales of analysis, including technological, processual, and application (Brey 2012; Ananny 2016; Floridi and Taddeo 2018). It makes visible, early on, the potential dilemmas and tensions faced by end-users and stakeholders in the uptake of the new technology so that risks can be mitigated to the greatest extent possible and to support ethically aware future use. The results at this stage are thus more abstract and conceptual, describing little in concrete solutions.

The process began by developing an understanding of the IN-PREP technology by interviews with the technology partners and working with them to map high-level information flows, such as what information is collected and shared, how it will be used, and how quality is assessed. It proceeded with desk studies and participation in user requirements workshops to identify key ethical risks and related harms. It ended with stakeholder consultation, via an end-user workshop to validate these initial findings and to begin to identify mitigation measures and solutions that would be relevant to system design and organisational practice. The workshop included twenty-one participants, a mix of external stakeholder experts and IN-PREP's technology and end-user partners. The end-users included experts in Civil Protection, Fire & Rescue, Police, Crisis and Disaster Risk Management, Disaster Relief, and Public Crisis Management from eight different EU Member States. In addition, six technology partners participated to incorporate technical potential to better anticipate outcomes where tools and practices meet.

What follows are some of the initial tensions identified in the literature and these interactions around the mundane decisions that are necessary to make diverse data talk across borders and around making data mean when managing different cultures of risk.

MAKING DATA TALK ACROSS BORDERS

When building this IT, designers are able to combine a variety of data, manage their translations from one format to another, and map them together onto a common operating picture. These mundane design decisions about which data format to use or which terminology to adopt when describing data, decisions that are often made for practical and efficacy reasons, have the ability to both empower and disempower actors and communities as different data and practices with data are included and excluded from consideration (Leonelli, 2016). Choosing one classification scheme over another risks power struggles and exclusion (e.g. missing a race or ethnicity category). Choosing all schema for the sake of inclusion risks bringing communication between organisations into discord and confusion (e.g. so many different interpretations it is impossible to know which one is intended). Data needs structure, and coordination acts needs common reference points, but the answers are not to be found in the ability to share data itself.

When working with such IT, the end-users want to ask complex question of the data that go beyond layering and comparisons. Tensions starts to emerge around what they want to do with the data as they move from questions like 'what data might they need to know?' and 'what situations they might encounter?' towards questions like 'who could be the most vulnerable?' and 'what socio-economic elements could exacerbate a crisis?'. It is already well acknowledged among disaster practioners that what risk means is not the same on two sides of a border, and thus what data they use and how they use similar data to answer these questions differ (Abad et al., 2018). As a

result, for the data to talk together, design and use has to be able to navigate these ethical tensions in how they can be put to use towards answering these different questions in different risk contexts.

At the most basic level, for example: in Germany, responders will first attend to those in need of aid, then they will attend to the safety of the scene: the greater risk is the immediate lives lost. In France, it is the other way around, first the scene is secured, then those that are in need of aid: the greater risk is to the ability to provide service, if the first responders are injured, then no one will be helped. In England, the aim is to remove all victims from the scene so both scene and person can be treated separately. Differences in what is required of data can be similarly exacerbated by different organisational and role-based approaches to disaster management. While most European countries work with a command and control model that has three levels, strategic, operational, and tactical, the responsibilities at each level are not consistent. For examples, decisions taken by a tactical team in the Netherlands can be taken by an operational team in Italy. What keeps coming out when responders from different places engage with each other is the basic question "why are you doing it that way?". Each practice of risk management has different data that is immediately relevant and highest priority: data about the scene, context, broader picture; data about who is where and in what condition; data about who has the capacity to take victims. Each require the data to be able to be focused and organised depending on the goal of the actor. This does not imply that these goals are by their nature conflicting (they are not), but the different aims ask for different IT work with the data beyond the ability for them to be comparable. When responders engage with such a system, they need to know, for example, if relating their understanding of social vulnerability to another organisation's data on infrastructural instability is an accurate and relevant association to make and to understand how that association might need to be made differently in one locale to the next.

The manner in which data can be approached to answer these questions matters because, as previous studies have demonstrated, decisions taken during disasters can "reinforce, intensify and produce new and uneven stratifications" (Adey 2016: 42). But, as Mark Latonero notes, "the very introduction of data-centered technologies can both reveal and exacerbate power relations on the ground."[1] If a responder or a model they use assumes specific identifiers for vulnerability – such as poverty, lack of robust utility services, dense housing – but in a specific context vulnerability is exacerbated by disability and unique religious tensions, then the inequalities that already existed in these less well represented features start to have greater weight and impact on those living in that context. Yet, it is not always possible to see the details in even the most well-structured big data from across the border. Nor are actors always aware of their interests when they decide on how they structure and categorise data (Ackerman et al., 2013). Both the end-users and technology designers often have a "less-than-complete understanding of the assumptions and values shaping the data they are working with" (Neff et al., 2017: p. 88). And, users of the designed technologies will often have different expertise and priorities when handling the data. It does not help that it is also very hard to predict what information will be available and relevant at what time for which organisation (Ley et al., 2014).

When working at the intersection of multiple risk practices, the challenge becomes one of choosing what kind of knowledge gets included in a system of classification and standards to be able to support and enhance successful collaborative decision-making, without erasing all diversity and ambiguities for the sake of making things common enough for all. Thus, the ability to assign value to the data is not determined by the data itself but by ever-shifting contexts and situations of use (Leonelli, 2016). Identifying these perspectives and accommodating what various actors need to know versus what is nice to know, what tools they must have versus may have, requires careful and considered design (Radianti et al., 2018). Meta-data is a start but cannot provide for all these uncertainties nor can it anticipate the informational needs of other organisations in advance.

The reach of these technologies across socio-political, cultural, and organisational divides demands articulation mechanisms by which actors are able to be aware of others, express difference, and align activities (Doherty, 2012). This awareness can in part be achieved by including a diversity of data and localised sources in the design process to ensure the work done with the data (through algorithms, translations, layering) is generalisable in ways that produce collaborative environments (GFDRR, 2018). But reconciling this diversity, particularly in the face of unpredictability, sets out new forms of responsibilities. Understanding the diversity involved is a vital step in supporting equity and inclusion but does not in and of itself build solidarity or an understanding of responsibility within the collaborations being pursued through the system. Care fundamentally involves critical commitments not just in the acts with the data but the processes of curating the data for multiple audiences and situations of use and involves a unique responsibility to produce and maintain the awareness of where one stands in relations to others. It is necessary to understand how one's data and one's acts with data fit into the broader picture and how specific engagements with that data build trust (Baker and Karasti, 2018).

[1] https://responsibledata.io/2015/06/22/emerging-responsible-data-questions-for-human-rights-and-human-security/

MAKING DATA MEAN ACROSS BORDERS

In order for the data to be technologically combined together, there needs to be an underlying ontology, grounded in some form of shared standards and classification system. But standards and classification systems for data sharing carry with them value systems, systems that guide behaviour, preferences, and implicit bias within a given society (Bowker et al., 2010). Data bias is not an ethical challenge unique to border situations. In fact, it is increasingly being accepted as inevitable and necessary; data systems and the categories upon which they function are just approximations of the world, helping those looking to pay attention in specific ways (GFDRR, 2018). All humans work with some form of implicit biases as ordering mechanisms to make sense of the world around them. And, not all bias or disparate impacts are bad. But putting borders between different entrenched cultures of bias together create new urgencies, such as avoiding mission creep or discrimination. It also presents new opportunities, through comparison, to make visible the otherwise tacit and implicit for interrogation.

The biases can be amplified in how community data, like the demographics of crime or who engages with specific public services, are known to often over- and under-represents communities. For example, low-income communities tend to be surveilled to a greater extent than high-income neighbourhoods, leading to disproportionate representation (Narayanan and MacDonald, 2019). While none of this data is inaccurate in and of themselves, inequalities emerge in how data becomes actionable information for specific actors, with the potential to make some segments of society better off or magnifying injustice for others (Powles and Nissembaum, 2018; Vallor et al., 2018). An added challenge with these transboundary tools is that there are so many actions being done with data and to the data in order to get different answers for different questions in different situations, that to design a system that can address these will be so complex that transparency becomes unrealistic for the users.

Yet, many disaster response agencies lack the technological and data skills and comparative capacities to ensure data and insights are accurate, credible, and not misleading for those they are sharing it with (Campo et al., 2018). When the quantity of data is so great that it is impossible for a person to process, actors need greater support in determining the proportionality and legitimacy of their actions with the data. To know if these systems are meeting specific needs and if their acts are accountable, actors need transparency: an understanding of what is being done with the data and why they received specific results with that data. But this is easier said than done, as exemplified in an exchange during one of the workshops:

> Responder: So when what we do changes, how do we make the models match?
> Designer: New rules would have to be able to be added to the system.
> Responder: How? Who would do that?
> Designer: You could tell us the new rules so we can add it in.
> Responder: But we don't understand what rules are there. How do we know how to make a rule?

The more accurate the algorithm is to transboundary interactions, the more complex it is and thus less able to be made transparent or intelligible by those making decisions with the systems. A lack of understanding in how the systems works means a greater reliance on this 'designed' foundation of action. It risks users being unaware of the limits of their view and experience of the data (House of Lords Select Committee on Artificial Intelligence 2018). Use of such systems require a level of data preparedness, technological knowledge, and knowledge on how to incorporate local and remote data activities into current practices (Baker and Karasti, 2018; Haak et al., 2018). This also magnifies bias discrimination and inequality, particularly in respect to underprivileged communities who have less access to such training and education (European Political Strategy Centre, 2018).

This puts actors in a difficult position of managing, without full information, the tension between using algorithms to make decisions more accurate in solidarity with others and ensuring fair treatment of those being served by making decisions that are locally relevant but potentially inaccurate for others (Whittlestone et al., 2019). With incomplete transparency or transparency that is full but too complex to be understood by a human, it is hard for users to understand when a model is insufficient for the required decisions or for the public to understand why certain groups get aid and others do not (GFDRR, 2018). This also makes trust problematic (Buscher et al., 2013). These are not simple decisions that can be tick-boxed away, but fundamentally part of understanding what is at stake in a collaboration, in a joint response, and when faced with simultaneously transboundary and local responsibilities.

Addressing bias is a social problem and not just a computational problem (Powles and Nissembaum, 2018). It involves envisioning the technical ecosystem, the full context, social forces, and purpose to which a technology is put to use (Vallor et al., 2018). While meta-data can help, it is difficult to produce the kind of background information useful to explain the data to help alleviate bias in advance of the information being exchanged. When

a responder learns how to engage with information, they learn it in a specific context -- national, cultural, institutional. This interpretive context helps people notice, determine, and improve the relevance, quality, timeliness, appropriateness, and compatibility of the data provided in the system (Bertelsen and Bødker, 2001). Understanding how categories were arrived at could help end-users see that a specific segment of the population would go unrepresented. It helps actors understand the 'how' and 'why' of information they are working with and avoid translating data inconsistencies into societal vulnerabilities (Dawes and Gharawi, 2018).

CONCLUSION

A focus on transboundary in disaster IT shows that for such systems to really work and support ethical decision-making and actions, they have to find ways to put that boundary forward. The IT becomes a starting point for a whole host of political engagements with ethical ramifications. Actors involved in the design and use need to learn how to be data allies, not just data sharers. Ethical standards are contextual and thus what is "good" in one context might not be in another and, as such, standards are not code-able or pre-definable in transboundary situations. As a result, the data, the structure of the systems it passes through, and the goals for its use need to become sites for deliberation (Neff et al., 2017). It might not be possible to take apart all the different classification systems to make sure they are ontologically representative (though they should still be, as much as possible). Nor it is possible to provide transparency of category, code, and algorithm. But, putting boundaries at the centre opens up opportunities to design for contextual awareness and articulation mechanisms that support actors in weighing local benefit with collaborative solidarity. It also makes visible new ethical responsibilities, not just about managing one's own data for the sake of liabilities, but about caring about its reuse by others.

The meaning and impact of codes and practices can only be understood in full in their relationship to others (Ananny, 2015). However, consistency and stability of meaning is exceedingly difficult in transboundary disaster management. Thus, ethics here is not about deciding right from wrong, but about providing the tools that enable actors engaged with these IT to produce the necessary descriptive context and interactional practices for an actor to understand where they stand in relation to others and how their actions affect diverse, and sometimes not well known, communities around them. Looking at ethical obligations with a sensitivity towards their context specificity can show that some data uses that may not be acceptable within one context may be permissible in another or to another purpose (Vayena et al., 2015). It is not enough to rely on context encoded as metadata or to open up code for inspection; while these steps are necessary, they are not enough to produce accountability towards the broader societal experience (Ananny, 2015). This kind of broader awareness is made in active and interactive the use of the system, as actors constantly renegotiate the distinctions between responder data and societal data (Neff et al., 2017). It is made through a better understanding of technological capabilities and limitations in different ethical contexts (Whittlestone et al., 2019).

Trust in the designers is not enough for trust in a system. Trust in a system is not enough for "good" collaborations that benefit society at all scales. Rather, mutual trust is built on shared context and coordination (Doherty, 2012). This comes from proactive engagement with the broader stakeholder and societal context, including activities to incorporate different kinds of knowledge, perspectives, and goals to inform innovation trajectories. In some respects, to understand the importance of different forms of interpretability in different situations, engagement with the system needs to reflect the interactive perspective and active participation often taken on by Liaisons or, as Princen et al. (2016) term it, Reginauts.

What is needed in the meantime is the ability to identify and see places where differences exist. Instead of aiming for an unreal transboundary ideal of no-bias and complete consensus in the abstract, the aim is then to use the diversity and discrepancies to make bias open for interrogation, in context. Maybe, then, though hopelessly idealistic, this kind of socio-technical work can become a starting point for understanding how to better address larger human rights challenges that increase societal resilience rather than merely act as amplifiers of bias and inequalities.

ACKNOWLEDGMENTS

The research presented here is part of the IN-PREP projects, funded by Horizon 2020 (H2020/2014-2020), the European Union's Programme for Research and Innovation under grant agreement n° 740627. I am grateful to my colleagues in this project for many inspiring conversations.

REFERENCES

Abad, J., Booth, L., Marx, S., Ettinger, S. and Gérard, F. (2018) Comparison of national strategies in France,

Germany and Switzerland for DRR and cross-border crisis management. *Procedia engineering*, 212, 879-886.

Ackerman, M. S., Dachtera, J., Pipek, V., and Wulf, V. (2013) Sharing knowledge and expertise: The CSCW view of knowledge management. *Computer Supported Cooperative Work,* 22, 4-6, 531-573.

Adey, P. (2016) Emergency Mobilities, *Mobilities*, 11, 1, 32-48, doi: 10.1080/17450101.2015.1103533

Ananny, M. (2016) Toward an ethics of algorithms: Convening, observation, probability, and timeliness. *Science, Technology, & Human Values*, 41, 1, 93-117.

Backman, S. and Rhinard, M. (2018). The European Union's capacities for managing crises. *Journal of contingencies and crisis management*, *26*(2), 261-271.

Baker, K. S. and Karasti, H. (2018) Data care and its politics: designing for local collective data management as a neglected thing. In *Proceedings of the 15th Participatory Design Conference: Full Papers-Volume 1*, ACM.

Bertelsen, O. W., and Bødker, S. (2001) Cooperation in massively distributed information spaces. In ECSCW01 Proceedings of the seventh conference on European Conference on Computer Supported Cooperative Work. Kluwer Academic Publishers. 1–17. Retrieved from http://portal.acm.org/citation.cfm?id=1241868

Bharosa, N., Lee, J., Janssen, M. and Rao, H. R. (2012) An activity theory analysis of boundary objects in cross-border information systems development for disaster management. *Security Informatics*, 1, 1, 15.

Bowker, G. C., Baker, K., Millerand, F., and Ribes, D. (2010) Toward information infrastructure studies: Ways of knowing in a networked environment. In International handbook of internet research, 97-117. Springer: Netherlands.

Brey, P. (2000) Disclosive Computer Ethics. *Computers and Society*, 30, 4, 10-16.

Brey, P. (2012). Anticipating Ethical Issues in Emerging IT. *Ethics and Information Technology,* 14, 305-317.

Buscher, M., Perng, S., and Wood, L. (2013). Privacy, Security, Liberty: Informing the Design of EMIS. In T. Comes, F. Fiedrich, S. Fortier, J. Geldermann, & L. Yang (Eds.), *Proceedings of the 10th International ISCRAM Conference – Baden- Baden, Germany*
http://eprints.lancs.ac.uk/62141/1/ELSI_FP_Privacy_pre_final.pdf

Cabane, L. and Lodge, M. (2018) Dealing with transboundary crises in the European Union: options for enhancing effective and legitimate transboundary crisis management capacities. TransCrisis, London, UK.

Campo, S. R., Howarth, C. N., Raymond, N. A. and Scarnecchia, D.P. (2018) The Signal Code: Ethical Obligations for Humanitarian Information Activities. Signal Program on Human Security and Technology, Standards and Ethics Series: 03. Harvard Humanitarian Initiative: Cambridge.

Dawes, S. and Gharawi, M. (2018) Transnational public sector knowledge networks: A comparative study of contextual distances. Government Information Quarterly, 35, 2, 184-194. https://doi.org/10.1016/j.giq.2018.02.002.

Doherty, G., Karamanis, N., and Luz, S. (2012) Collaboration in translation: The impact of increased reach on cross-organisational work. *Computer Supported Cooperative Work (CSCW)*, *21*(6), 525-554.

European Political Strategy Centre. (2018) Report from the High-Level Hearing 'A European Union Strategy for Artificial Intelligence'. https://ec.europa.eu/epsc/sites/epsc/files/epsc_-_report_-_hearing_-_a_european_union_strategy_for_artificial_intelligence.pdf

Fiore-Gartland, B. and Neff, G. (2015) Communication, mediation, and the expectations of data: Data valences across health and wellness communities. *International Journal of Communication*, 9, 19.

Floridi, L. and Taddeo, M. (2018) What is data ethics?, *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 374, 2083.

Floridi, L. (2018) Soft Ethics and the Governance of the Digital, *Philosophy & Technology,* 31, 1, 1–8.

GFDRR. (2018) Machine Learning for Disaster Risk Management. Washington, DC: GFDRR.

Hijmans, H. and Raab, C. (2018) Ethical Dimensions of the GDPR. in: Mark Cole and Franziska Boehm (eds.) *Commentary on the General Data Protection Regulation.* Cheltenham: Edward Elgar.

Haak, E., Ubacht, J., Van den Homberg, M., Cunningham, S., and Van den Walle, B. (2018) A framework for strengthening data ecosystems to serve humanitarian purposes. In *Proceedings of the 19th Annual International Conference on Digital Government Research: Governance in the Data Age*, ACM: New York. DOI: https://doi.org/10.1145/3209281.3209326

House of Lords Select Committee on Artificial Intelligence. (2018) AI in the UK: ready, willing and able?

Report of Session 2017–19: HL Paper 100. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiHnZDp1t3bAhXDcsAKHVe8CgUQFggpMAA&url=https%3A%2F%2Fpublications.parliament.uk%2Fpa%2Fld201719%2Fldselect%2Fldai%2F100%2F100.pdf&usg=AOvVaw1ORsnbqvCmu_cetDlwpjLU

Jasmontaite, L., Delprato, U., Jager, B., and Neubauer, G. (2015) Challenges for the Use of Information Technology and Standards in International Disaster Management. *Proceedings of Future Security 2015*, 129-136.

Kloza, D., Van Dijk, N., Gellert, R., Böröcz, I., Tanas, A., Mantovani, E. and Quinn, P. (2017) Data Protection Impact Assessments in the European Union: complementing the new legal framework towards a more robust protection of individuals. d.*pia.lab Policy Brief*, 1/2017.

Leonelli S. (2016) Locating ethics in data science: responsibility and accountability in global and distributed knowledge production systems. *Phil. Trans. R. Soc. A,* 374, 1-12. http://dx.doi.org/10.1098/rsta.2016.0122

Ley, B., Ludwig, T., Pipek, V., Randall, D., Reuter, C., and Wiedenhoefer, T. (2014) Information and expertise sharing in inter-organizational crisis management. *Computer Supported Cooperative Work (CSCW)*, 23, 4-6, 347-387.

Muhren, W. J., and van de Walle, B. A. (2010) Sense-making and information management in emergency response, *Bulletin of the American Society for Information Science and Technology*, 36, 5, 30-33.

Narayanan, A. and MacDonald, G. (2019). Toward an Open Data Bias Assessment Tool: Measuring Bias in Open Spatial Data. *Urban Institute working paper. https://www.urban.org/research/publication/toward-open-data-bias-assessment-tool/view/full_report*

Neff, G., Tanweer, A., Fiore-Gartland, B., and Osburn, L. (2017) Critique and contribute: A practice-based framework for improving critical data studies and data science. *Big Data*, 5, 2, 85-97.

Panten, K., van Heel, B. F., Fliervoet, J. M., and van den Born, R. J. (2018) Cross-Border Collaboration in River Management: Views on Participation in a Dutch-German Case Study. *Water resources management*, 32, 12, 4063-4078.

Powles, J. and Nissenbaum, H. (2018) The Seductive Diversion of 'Solving' Bias in Artificial Intelligence. *Medium*. https://medium.com/s/story/the-seductive-diversion-of-solving-bias-in-artificial-intelligence-890df5e5ef53

Pottebaum, J., Schäfer, C., Kuhnert, M., Behnke, D., Wietfeld, C., Büscher, M., and Petersen, K. (2016) Common information space for collaborative emergency management. In *2016 IEEE Symposium on Technologies for Homeland Security (HST)*, 1-6.

Princen, S., Geuijen, K., Candel, J., Folgerts, O., and Hooijer, R. (2016) Establishing cross-border co-operation between professional organizations: Police, fire brigades and emergency health services in Dutch border regions. *European Urban and Regional Studies*, 23, 3, 497-512.

Radianti, J., Martinez, S., Munkvold, B. E., and Konnestad, M. (2018) Co-designing a virtual training tool for emergency management. In *The 15tn International Conference on Information Systems for Crisis Response and Management*.

Stahl, Bernd Carsten (2013) Responsible research and innovation: The role of privacy in an emerging framework, Science and Public Policy 40, pp. 708–716.

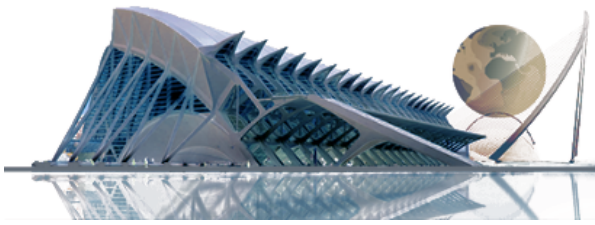
Vallor, S., Green, B. and Raicu, I. (2018). Ethics in Technology Practice. The Markkula Center for Applied Ethics at Santa Clara University. https://www.scu.edu/ethics/

Vayena E, Salathé M, Madoff LC, Brownstein JS (2015) Ethical Challenges of Big Data in Public Health. PLoS Comput Biol 11(2): e1003904. https://doi.org/10.1371/journal.pcbi.1003904

Whittlestone, J. Nyrup, R. Alexandrova, A. Dihal, K. and Cave, S. (2019) Ethical and societal implications of algorithms, data, and artificial intelligence: a roadmap for research. London: Nuffield Foundation.

Williams, S., Hardy, C., and Nitschke, P. (2019) Configuring the Internet of Things (IoT): A Review and Implications for Big Data Analytics. In *Proceedings of the 52nd Hawaii International Conference on System Sciences*.

Wright, D. (2015) Ethical Impact Assessment. in J. Holbrook & C. Mitcham (eds.), *Ethics, Science, Technology and Engineering: A Global Resource*, 2nd edition, Macmillan Reference: MI.



ISCRAM 2019
16 TH INTERNATIONAL CONFERENCE ON INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

Track 4.

Logistics and Supply Chain Management in Crisis Response

Chairs

Bernd Hellingrath, *University of Muenster, Germany*

Gyöngyi Kovács, *Hanken University, Finland*

Adam Widera, *University of Muenster, Germany*

Towards Social Media Decision Support for Joined EMS and Crisis Logistics

Kathrin Eismann
University of Bamberg
kathrin.eismann@uni-bamberg.de

Melanie Reuter-Oppermann
Karlsruhe Institute of Technology
melanie.reuter@kit.edu

Kai Fischbach
University of Bamberg
kai.fischbach@uni-bamberg.de

ABSTRACT

In this paper, we investigate how social media can be utilised to support the integration of emergency medical services (EMS) and crisis management activities. We explore the literature both on social media in crisis management and on EMS logistics to elaborate on their potential to support EMS logistics planning based on the experiences from crisis management. We then discuss how social media data can be used for tactical and strategic decision-making using location data to improve demand forecasting and planning for both routine emergencies and crises.

Keywords

Crisis Logistics, EMS Logistics, Social Media, Decision-Making.

INTRODUCTION

Recent statistics illustrate the continued relevance of research in crisis and disaster management. The United Nations Office for Disaster Risk Reduction finds that between 1998 and 2017, natural disasters caused 1.3 million fatalities and otherwise affected 4.4 million people (Wallemacq and House, 2018). While reports indicate an overall decline in the number of human-made catastrophes, the number of natural crises and disasters, such as hurricanes, wildfires, and earthquakes, continues to increase (Swiss Re Institute, 2018).

This sheds light on the crisis and humanitarian logistics required to attenuate the impacts of crisis events for people and communities that are affected (van Wassenhove, 2006). However, crisis and humanitarian supply chains, just like other systems involved in crisis response, often suffer from information flow impediments, including the unavailability and unreliability of information, with potentially serious implications for crisis response (Altay and Labonte, 2014; Day *et al.*, 2009; Maitland *et al.*, 2009). This is particularly evident when it comes to emergency medical services (EMS), which are expected to serve routine emergencies (e.g., traffic accidents and medical emergencies), but at the same time also to participate in crisis response activities.

In the crisis informatics field, the question of how information and communication technologies and particularly social media – Web 2.0 platforms such as content-sharing sites, microblogs, and online social networks that provide a forum for user-generated content and that are open to modification, participation, and collaboration by its users (Kaplan and Haenlein, 2010) – can assist in the coordination of crisis management efforts within and across different agencies has received much attention (Meum and Munkvold, 2013; Sarcevic *et al.*, 2012; Yates and Paquette, 2011). Taking up this question, we investigate how social media can specifically support the integration of routine EMS and crisis management activities.

Our research questions can be formulated as follows: *How can social media support decision-making in EMS logistics relating to crisis management activities? What is the potential of and opportunities for using social media as input for planning problems, and what are the limitations and risks?*

To answer these questions, we combine the existing literature on social media in crisis management and on EMS logistics. We draw on prior research on both crisis and humanitarian logistics, as both branches often face similar tasks and challenges (Zhang *et al.*, 2002). We then match the planning levels for EMS logistics with the crisis management phases to elaborate on the potential of social media to support EMS logistics planning based on the experiences from crisis management. We explain how social media data can be used at both the tactical and strategic decision levels – for example, using location data to improve demand forecasting and planning for both routine emergencies and crises.

The remainder of the paper is structured as follows. In the next section, we describe the research problem in detail. We then illustrate how social media might be used to support EMS and crisis logistics decision-making, considering operational as well as tactical and strategic decisions in crisis mitigation, preparedness, response, and recovery. Based on this, we present a use case for illustration and a research proposal at the strategic-tactical level. We conclude with a summary of our work and prospects for future research.

RESEARCH PROBLEM

Many different parties and service providers are needed to address a crisis event adequately, including EMS, firefighters, and police (van Borkulo *et al.*, 2005). The EMS system is designed to meet the requirements of everyday service, but also to be available during crises. Given that, it stands to reason that preparations for potential crises should take everyday EMS activities into account.

This is especially true for EMS logistics, which are an essential aspect of crisis management (Kovács and Spens, 2007). Decisions that relate to facility location, relief distribution, or casualty transportation – such as locating and relocating ambulances, setting up dispatching and routing policies, and coordinating with other actors involved in crisis management – are essential for dealing with a crisis (Caunhye *et al.*, 2012).

Thus, responding to a crisis inevitably requires EMS logistics planning, including decisions at the *operational, tactical, and strategic levels*, as Table 1 summarises (Reuter-Oppermann *et al.*, 2017).

Table 1: Overview of EMS logistics

Planning level	Time horizon	EMS planning problems
Strategic	Yearly or longer	Locating bases Determining the number of ambulances Hiring crew Long-term demand forecast
Tactical	Weekly or monthly	Locating ambulances Staff scheduling Scheduling emergency medical physicians
Operational	Daily	Relocating ambulances Assigning ambulances to calls Daily demand forecast Patient transport scheduling Handling unavailability of staff and vehicles

At the strategic level, much research on EMS logistics has focused on models and approaches for locating bases. Once opened, a base typically is in use for several years or even decades. Decisions about acquiring new ambulances are often made annually, but once purchased ambulances are expected to be in use for many years. However, as ambulances can be transferred easily between base locations, decisions on where to put them are made at the tactical level. Similarly, the schedules of emergency medical physicians, who are a constituent part of the EMS systems of several European countries, are determined tactically. At the operational level, planning addresses relocating and dispatching ambulances, as well as scheduling patient transports (Reuter-Oppermann *et al.*, 2017). EMS logistics decisions are thus an essential prerequisite of crisis management as they determine what resources can be mobilised when a crisis occurs (Bui *et al.*, 2000).

EMS logistics activities can be assigned to the four stages of crisis management (Altay and Green III, 2006; Galindo and Batta, 2013). They include: *crisis mitigation* and *crisis preparedness* activities aimed at preventing the occurrence of a crisis, limiting its impacts, and providing resources to respond to an event before it takes place; *crisis response* activities intended to minimise its acute impacts; and *crisis recovery* activities in the post-event stage, such as rebuilding physical infrastructures (Lindell, 2013).

The literature on EMS logistics in crisis mitigation and recovery has focused mainly on strategic decision-making, whereas the tactical and operational levels are considered more often in the context of crisis preparedness and response operations (Leiras *et al.*, 2014). In the pre-event stages, recruiting and training personnel, prepositioning ambulances and emergency supplies, and setting up long-term working relationships with other crisis responders is essential (Altay and Green III, 2006; Bui *et al.*, 2000; Goldschmidt and Kumar, 2016). During crisis response, EMS logistics often serve operational tasks, such as evacuating threatened populations, opening shelters, and providing mass emergency medical care (Altay and Green III, 2006). During crisis recovery, the focus of EMS logistics is on the tactical reduction of resources (Pettit and Beresford, 2005), but operational tasks, such as providing sustained mass care, and strategic activities surrounding the adjustment of existing tools and procedures are addressed as well (Altay and Green III, 2006; Bui *et al.*, 2000).

Demand prediction is a major challenge for EMS logistics in crisis management (Kovács and Spens, 2009). While rare, crisis are potentially catastrophic events associated with a high degree of uncertainty of occurrence, which means that the potential for crisis planning is limited (Boin and McConnell, 2007). Despite the occasional nature of events, sufficient EMS resources such as ambulances and paramedics must be available immediately at the onset of a crisis. This need competes with the fact that it is not feasible to install more resources than necessary for everyday service provision due to high cost pressures in many healthcare systems. Furthermore, even during a crisis, routine emergencies (e.g., traffic accidents and medical emergencies) still need to be served by EMS. It is thus unsurprising that the integration of EMS logistics and other systems is considered a prime challenge of crisis management (Gupta *et al.*, 2016).

To ensure the functionality of the crisis response system when it is needed, an efficient flow of information to and among all actors before, during, and after an event is essential (Day *et al.*, 2009; Maitland *et al.*, 2009). At the strategic level, incident data from previous years is a main input for EMS logistics planning and demand forecasting (e.g., of the expected locations and times of future emergencies [Ingolffson, 2013]). In addition, demographic information such as the number and ages of inhabitants in a district and the distribution of schools, nursing homes, and production sites can be taken into account. At the operational level, weather and current traffic are further data points. Beyond these inputs, social media and other sources of big data are expected to facilitate demand forecasting (Starr and van Wassenhove, 2014).

USING SOCIAL MEDIA TO SUPPORT EMS AND CRISIS LOGISTICS DECISION-MAKING

Prior research on social media in crisis management has emphasised the capability of platforms such as Facebook and Twitter to enhance decision-makers' *situational awareness*: by monitoring social media, they can learn about crisis events, including the location and extent of a hazard, newly developing threats and security risks, and the needs of affected communities (Eismann *et al.*, 2018). In addition, social media can assist decision-makers in obtaining contextual background knowledge to complement information from other sources. Thus, social media can support decision-makers in developing an overview of a crisis situation and establishing a sense of context (Ludwig *et al.*, 2015; Tapia and Moore, 2014).

We argue that social media can be considered *emergency response information systems* that enable EMS planners to collect information related to a crisis event (Turoff, 2002). In the following, we illustrate the promises and limitations of social media to enhance the flow of crisis-related information. Our assumption is that by supporting EMS planners in managing (i.e., collecting, processing, and sharing) information, social media can also enhance the integration of EMS logistics into crisis mitigation, preparedness, response, and recovery efforts (Maitland *et al.*, 2009; Saab *et al.*, 2008). Our argument is based on the premise that increased access to situational information can assist decision-makers in recognising decision problems (Bui *et al.*, 2000), while at the same time the actual relevance and meaning of this information depends on *environmental constraints*, such as the extent of situational uncertainty, complexity, and time pressure (Kapucu and Garayev, 2011), as well as the *time horizon* of a decision (Iakovou *et al.*, 1994).

Using Social Media to Support Operational EMS and Crisis Logistics Decision-Making

Operational EMS and crisis logistics decisions are often about routine tasks, such as the inspection and inventory of resources, but also include less-structured problems, such as monitoring potential information sources and coordinating assistance planning (Bui *et al.*, 2000). A key issue with such short-term decision-making is the lack of lead-time before decisions are made. *Timely access to relevant information* is generally not considered a problem for well-structured tasks (Thompson *et al.*, 2006), but operational decisions made during crisis response are known to suffer from a lack of timely and locally specific information, which cannot be provided by established sources of information because of the immediacy and unexpectedness of events and the lack or outage of local contacts and infrastructure (St. Denis *et al.*, 2014; van Gorp *et al.*, 2015). Yet under conditions of high situational complexity and uncertainty, decision-makers' need to consider a greater variety of

sources that provide general background information increases (Vakkari, 1999). By providing them with access to large amounts of near real-time information, social media can help fill these information gaps (Ludwig *et al.*, 2015; Sarcevic *et al.*, 2012; Tapia and Moore, 2014).

In addition, the *accuracy and representativeness of information* is essential for addressing short-term problems, which means that the evaluation and verification of data are major issues in decision-making (Fisher and Kingma, 2001; Thompson *et al.*, 2006). Using information from social media requires assessing the relevance and accuracy of that information under conditions of information overload and scarcity of time and other resources (Ludwig *et al.*, 2015). Moreover, operational – rather than strategic and tactical – crisis-response decisions are associated with high criticality, which means that trustworthiness of data is essential. Decision-makers may not, therefore, rely on available information to make decisions that have the potential to save or lose lives or that involve allocation of scarce resources, such as assigning vehicles and personnel for search and rescue operations. The findings of prior research suggest that social media data are usually at least triangulated with information from other, presumably more reliable sources (Tapia and Moore, 2014).

As regards operational decision-making, we observe that information from social media is likely of limited value for routine decision tasks for which alternative sources of relevant and high-quality information are available. For particularly urgent tasks, however, information overload and limited reliability of information can be problematic.

Using Social Media to Support Tactical and Strategic EMS and Crisis Logistics Decision-Making

Tactical and strategic EMS logistics decisions are most relevant during the pre- and post-event stages of a crisis, given that the acute impact phase of such events rarely lasts longer than a few days (Kumar and Havey, 2013) and decision-makers typically prefer making medium- and long-term decisions well in advance of a potential crisis (Danielsson and Ohlsson, 1999).

It is useful to distinguish between crises with a sudden onset, such as terrorist attacks, and events with a slow onset, such as droughts (Kumar and Havey, 2013): Whereas crisis preparedness is basically precluded for sudden-onset events, slow-onset events can be mitigated in the abstract and effective preparation is possible. In both cases, decisions made weeks or months before an event are likely to have ripple effects on crisis response activities because both the availability EMS capabilities and the flexibility of the EMS logistics system depend on prior planning (Thompson *et al.*, 2006).

Problems of timeliness and availability of relevant information are less severe at the strategic and tactical levels because a more extensive search for and vetting of potential information sources is feasible. Nonetheless, we find that there are still limitations to using social media to support medium- and long-term decision-making, as crisis planning involves many tasks that are well-specified in advance, such as defining roles and responsibilities and allocating materials and equipment, as well as activities that are restricted by organisational routines (Boin and McConnell, 2007).

Beyond that, evidence suggests that social media can provide decision-makers with *intelligence that is not available from other sources*, such as notifications about emerging security threats, newly developing crises, and other emergent conditions on the ground that could affect the safety of people and materials. If thoroughly vetted, such information can be useful for the tactical deployment of personnel and the location or relocation of vehicles and supplies, route choices, as well as strategic investment decisions regarding bases, local infrastructure, and alliances with other actors (Tapia and Moore, 2014). Furthermore, the literature suggests that information from social media can assist in long-term tasks aimed at increasing organisational and community resilience, such as reputation and community management (Anson *et al.*, 2017).

However, ambiguities in the interpretation of available information can hinder decision-makers from arriving at correct and consistent interpretations of a problem (Kowalski-Traklofer *et al.*, 2003). As the consequences of tactical and strategic decisions might not be observed until the actual occurrence of a crisis, which could be much later, this issue is particularly problematic for medium- and long-term EMS logistics decisions (Helsloot, 2005). Thus, reliability and especially the *accuracy, completeness, and consistency of available information* remain essential (Fisher and Kingma, 2001).

Overall, we are cautiously optimistic regarding the potential of social media to support EMS and crisis logistics integration in the medium and long runs. While many routine tasks might still not benefit from the additional information, social media can be used to obtain intelligence not available from other sources and to increase organisational and community resilience through timely engagement. The need for cross-validation is evident; the literature suggests that this can be done due to the extended planning horizon and the possibility to rely on crowdsourcing and interactive approaches to information collection and validation (Mehta *et al.*, 2017).

Summary

Figure 1 summarises our conclusions. Overall, it is unlikely for medium- and long-term decisions to be made while situational uncertainty and time pressure are high (Kumar and Havey, 2013). Due to the significant long-term impacts of such decisions, social media also do not recommend themselves as sources of information in such cases, given that baseline quality criteria might not be met and time pressures impede thorough validation of information.

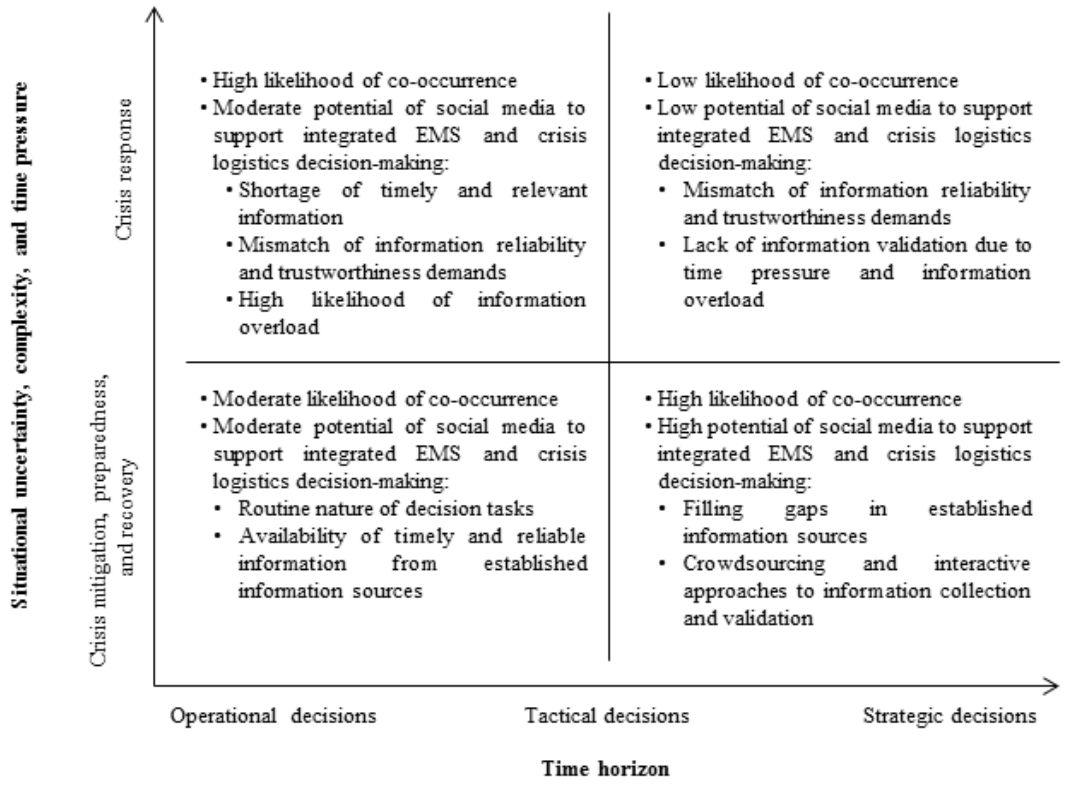


Figure 1 Potential of social media to support integrated EMS and crisis logistics decision-making

The less acute stages of a crisis are more similar to non-crisis EMS logistics (Holguín-Veras *et al.*, 2012). Based on the research literature, we conclude that operational decisions before or after the crisis impact phase are often subject to established EMS routines and can be made using regular sources of information, which diminishes the potential of social media to contribute to these tasks.

We believe, however, that both tactical and strategic EMS logistics decision-making can benefit from incorporating social media, especially during crisis mitigation, preparedness, and recovery. Although the need to cross-validate information is evident for medium- and long-term decisions, too, the environmental conditions allow for more rigorous data collection and verification using more time-consuming methods. In particular, social media can support decisions that are not overly regulated by organisational norms and routines, such as those regarding investments in infrastructures, personnel, and networks of responders and potentially affected communities.

Contrary to our insights, prior research on social media in EMS and crisis and humanitarian logistics has mostly focused on operational decisions made in the response phase (Kirac and Milburn, 2018). Therefore, we suggest a use case for illustration and a research design to investigate further how social media can enhance EMS and crisis logistics integration based on strategic and tactical decisions, especially in mitigating and preparing for a sudden crisis event.

RESEARCH SCENARIO

Although prior literature has mostly focused on the use of social media for operational decision-making during crisis response, our insights demonstrate that it can also be used for tactical and strategic planning problems. On

the strategic level, decisions regarding where EMS ambulance and bases should be located are frequently investigated. In line with earlier approaches (van Essen *et al.*, 2013), we consider the planning problem of locating ambulances and bases both strategically and tactically.

Locating ambulances and bases serves several objectives that may, depending on the decisions made, lead to outcomes that are at odds with one another. These include, for example, maximising the coverage of the region or population, minimising driving times to emergency calls, maximising response time fulfilment, minimising costs for installing ambulances and bases, and maximising the survival probability of patients in case of an emergency (Reuter-Oppermann *et al.*, 2017). When deciding on locations for ambulances and bases, it is typical to take only everyday EMS demand into account (Steins *et al.*, 2019). Crisis mitigation and preparedness activities thus must be handled separately, using the locations of EMS vehicles as input. Nevertheless, these EMS decisions are likely to have ripple effects on how a crisis is dealt with in the acute response phase, which means that it is most promising to investigate the potential effects of integrating novel sources of information for integrated EMS and crisis logistics decision-making prior to an event. Our research proposal thus aims at integrating EMS and crisis logistics planning by considering the potential of information from social media to facilitate strategic and tactical decision-making in crisis mitigation and preparedness.

The research question of the proposed study is: *How does integrating social media into tactical and strategic EMS logistics decision-making for base and ambulance locations influence crisis response?*

The expected demand is the most important input parameter for this planning problem. Unfortunately, the occurrence of future emergencies is, by nature, uncertain. Based on historical data on the times and locations of past emergencies, future demands can be predicted with a certain probability using statistical and machine learning techniques (Steins *et al.*, 2019). Predictions could also benefit, potentially highly, from integrating novel sources of (big) data and information, such as social media (Starr and van Wassenhove, 2014).

The assumption is that significantly improved predictions cannot be obtained using currently available data; additional data are necessary for that (Steins *et al.*, 2019). It is obvious that emergencies can occur only where there are people, but it is not easy to determine with certainty where they may be at any given time of a given day. Census data can provide a zone's population, but we cannot know for certain when people are actually at home. We do not know generally where individuals within a population work, when they work, and where they spend their free time. We also do not have anywhere near precise knowledge about how many people go to shopping areas, city centres, and other public or private facilities, which routes they take, and which means of transportation they rely on. The planning problem is aggravated when having to account for a sudden crisis event, such as a terrorist attack or a major fire. In such cases, ambulances that would otherwise serve routine emergencies (e.g., traffic accidents, medical emergencies, and patient transport) are needed to respond to the events.

Social media can help EMS planners approach this challenge, using, for instance, location data from posts and tweets collected in advance (Hasan *et al.*, 2013), which could be beneficial in better estimating the actual number of people in an area for different months, weekdays, and also times of day. Combined with the actual number of emergencies in a zone and data obtained from other information sources, such as the density of active mobile phones in an area, such information could be used to estimate the relationship between the number of emergencies and the location of people to arrive at better forecasts of emergency events. Furthermore, social media data collected during a crisis event (de Longueville *et al.*, 2009), along with potentially available data from historical events in the same region, could be integrated into crisis mitigation and preparedness planning for future events.

POTENTIAL STUDY DESIGN

Our aim is to investigate how using location data from social media for strategic and tactical decision-making regarding the location of ambulances and bases influences crisis response activities. In particular, we want to investigate its effects on the estimated distances and driving times to expected emergency calls during a sudden crisis event (e.g., a terrorist attack) in a given zone.

We adopt a qualitative research approach based on the critical incident technique, which is a flexible method for investigating goal-directed behaviour in specific types of situations (Flanagan, 1954). Initially, a set of vignettes of the research scenario outlined in the previous section will be compiled. The vignettes will provide descriptions of the situation (i.e., responding to emergency calls during a sudden crisis event in a given zone) and the general aim of activity in that situation (i.e., minimising expected driving times and distances to emergency calls during crisis response). Using a vignette-based approach allows us to gain an in-depth understanding of the cognitive processes that guide respondents' decisions (Jenkins *et al.*, 2010).

We intend to compile a set of three vignettes to illustrate the critical incident. The first vignette will present the problem of locating ambulances and bases based on established data inputs, such as census and demographic data, historical incident data, and outputs of frequently used decision-support systems (Ingolffson, 2013). It will contain a description of the underlying planning problem in a fictive response zone, enriched by materials that further illustrate the zone, especially maps of the area, potential vehicle locations, and data inputs. The second vignette will introduce simulated location data from social media for the respective area to complement the first vignette by additional data input. The third vignette will enrich the scenario by the occurrence of a sudden crisis event. Again, supplementary materials to indicate the location and magnitude of the event will be displayed.

We then plan to use the vignettes to conduct semi-structured, qualitative, face-to-face interviews with EMS planners from rescue operation centres in Germany. All interviewees will be presented the vignettes in the order delineated above. For each vignette, interviewees will be asked to describe how they perceive the situation, how they would respond to it to achieve the stated aims, and what criteria would be relevant to their decision-making (Flanagan, 1954). Interviews will be recorded and transcribed to identify emergent themes, using the constant comparative method (Boeije, 2002). The number of interviewees is to be determined based on the theoretical saturation in an iterative data collection and analysis process (Bowen, 2008). To ensure the credibility and trustworthiness of results, the scenarios and vignettes will be discussed with at least two experienced EMS planners in advance. The outcomes of the study will be validated through discussions with domain experts and participant cross-checking (Butterfield *et al.*, 2005).

The results of the proposed study will demonstrate the potential of social media to support integrated EMS and crisis logistics decision-making in the tactical and strategic domain, which can serve as an input for future model development and testing.

CONCLUSION

Our goal is to evaluate the potential of social media as a complementary source of information to assist in the integration of EMS and crisis logistics decision-making. In this paper, we have investigated what prior research on social media in crisis management reveals about their capabilities to enhance the integration of EMS and crisis logistics. We find that social media are most likely to assist in that task for tactical and strategic decision-making – for instance, determining the location of ambulances and bases. The outcomes of these decisions can be used, in turn, as input in crisis mitigation and preparedness.

Based on our findings, we propose a research scenario and a potential study design to investigate how social media can be used to enhance tactical and strategic EMS logistics decision-making, and the implications of using social media in the pre-crisis stage for achieving crisis response outcomes. In our research proposal, we compare the outcomes of tactical and strategic ambulance and base location planning using established information sources (e.g., census and demographic data, historical incident data, and outputs of existing decision-support systems) with location data obtained from social media. We rely on vignette-based qualitative interviews using simulated data and a fictive area of operations in which a sudden crisis event (e.g., a terrorist attack) is imagined to take place. Apart from the potential of social media to support EMS and crisis management integration, the outcomes of the proposed study will also shed light on the limitations and trade-offs of social media with respect to information collection, forecasting, and (automated) information processing.

Future research might expand this approach by collecting social media data for a specific EMS region that can be used to update the expected demand for future EMS. Furthermore, decision models that take such data into account for strategic and tactical planning problems, such as locating ambulances and bases, or for operational tasks such as dispatching and relocating ambulances and scheduling patient transports to, from, or between hospitals, can be developed and integrated into decision-support tools for EMS planning based on the prospective results of our work.

REFERENCES

Altay, N. and Green III, W.G. (2006) OR/MS Research in Disaster Response Operations Management, *European Journal of Operational Research*, 175, 1, 475–493.

Altay, N. and Labonte, M. (2014) Challenges in Humanitarian Information Management and Exchange: Evidence from Haiti, *Disasters*, 38, s1, S50–S72.

Anson, S., Watson, H., Wadhwa, K., and Metz, K. (2017) Analysing Social Media Data for Disaster Preparedness: Understanding the Opportunities and Barriers Faced by Humanitarian Actors, *International Journal of Disaster Risk Reduction*, 21, 131–139.

Boeije, H. (2002) A Purposeful Approach to the Constant Comparative Method in the Analysis of Qualitative Interviews, *Quality and Quantity*, 36, 4, 391–409.

Boin, A. and McConnell, A. (2007) Preparing for Critical Infrastructure Breakdowns: The Limits of Crisis Management and the Need for Resilience, *Journal of Contingencies and Crisis Management*, 15, 1, 50–59.

Bowen, G.A. (2008) Naturalistic Inquiry and the Saturation Concept: A Research Note, *Qualitative Research*, 8, 1, 137–152.

Bui, T., Cho, S., Sankaran, S., and Sovereign, M. (2000) A Framework for Designing a Global Information Network for Multinational Humanitarian Assistance/Disaster Relief, *Information Systems Frontiers*, 1, 4, 427–442.

Butterfield, L.D., Borgen, W.A., Amundson, N.E., and Maglio, A.T. (2005) Fifty Years of the Critical Incident Technique: 1954-2004 and Beyond, *Qualitative Research*, 5, 4, 475–497.

Caunhye, A.M., Nie, X., and Pokharel, S. (2012) Optimization Models in Emergency Logistics: A Literature Review, *Socio-Economic Planning Sciences*, 46, 1, 4–13.

Danielsson, M., and Ohlsson, K. (1999) Decision Making in Emergency Management: A Survey Study, *International Journal of Cognitive Ergonomics*, 3, 2, 91–99.

Day, J.M., Junglas, I., and Silva, L. (2009) Information Flow Impediments in Disaster Relief Supply Chains, *Journal of the Association for Information Systems*, 10, 8, 637–660.

de Longueville, B., Smith, R.S., and Luraschi, G. (2009) 'OMG, from Here, I Can See the Flames!': A Use Case of Mining Location Based Social Networks to Acquire Spatio-Temporal Data on Forest Fires. *Proceedings of the LBSN '09* (73–80), Seattle, WA.

Eismann, K., Posegga, O., and Fischbach, K. (2018) Decision Making in Emergency Management: The Role of Social Media, *ECIS 2018 Research Papers* (paper 152), Portsmouth.

Fisher, C.W. and Kingma, B.R. (2001) Criticality of Data Quality as Exemplified in Two Disasters, *Information and Management*, 39, 2, 109–116.

Flanagan, J.C. (1954) The Critical Incident Technique, *Psychological Bulletin*, 51, 4, 327–358.

Galindo, G., and Batta, R. (2013) Review of Recent Developments in OR/MS Research in Disaster Operations Management, *European Journal of Operational Research*, 230, 2, 201–211.

Goldschmidt, K.H. and Kumar, S. (2016) Humanitarian Operations and Crisis/Disaster Management: A Retrospective Review of the Literature and Framework for Development, *International Journal of Disaster Risk Reduction*, 20, 1-13.

Gupta, S., Starr, M.S., Farahani, R.Z., and Matinrad, N. (2016) Disaster Management from a POM Perspective: Mapping a New Domain, *Production and Operations Management*, 25, 10, 1611–1637.

Hasan, S., Zhan, X., and Ukkusuri, S.V. (2013) Understanding Urban Human Activity and Mobility Patterns Using Large-Scale Location-Based Data from Online Social Media, *Proceedings of the UrbComp '13* (paper 6), Chicago, IL.

Helsloot, I. (2005) Bordering on Reality: Findings on the Bonfire Crisis Management Simulation, *Journal of Contingencies and Crisis Management*, 13, 4, 159–169.

Holguín-Veras, J., Jaller, M., van Wassenhove, L.N., Pérez, N., and Wachtendorf, T. (2012) On the Unique Features of Post-Disaster Humanitarian Logistics, *Journal of Operations Management*, 30, 7–8, 494–506.

Iakovou, E., Douligeris, C., and Korde, A. (1994) A Synthesis of Decision Models for Analysis, Assessment, and Contingency Planning for Oil Spill Incidents, *Omega*, 22, 5, 457–470.

Ingolffson, A. (2013) EMS Planning and Management, in Zarik, G. (ed.) *Operations Research and Health Care Policy* (105–128), Springer, New York, NY.

Jenkins, N., Bloor, M., Fischer, J., Berney, L., and Neale, J. (2010) Putting It in Context: The Use of Vignettes in Qualitative Interviewing, *Qualitative Research*, 10, 2, 175–198.

Kaplan, A.M. and Haenlein, M. (2010) Users of the World, Unite! The Challenges and Opportunities of Social Media, *Business Horizons*, 53, 1, 59–68.

Kapucu, N. and Garayev, V. (2011) Collaborative Decision-Making in Emergency and Disaster Management, *International Journal of Public Administration*, 34, 6, 366–375.

Kirac, E. and Milburn, A.B. (2018) A General Framework for Assessing the Value of Social Data for Disaster Response Logistics Planning, *European Journal of Operational Research*, 269, 2, 486-500.

Kovács, G. and Spens, K. (2007) Humanitarian Logistics in Disaster Relief Operations, *International Journal of Physical Distribution and Logistics Management*, 37, 2, 99–114.

Kovács, G. and Spens, K. M. (2009) Identifying challenges in humanitarian logistics, *International Journal of Physical Distribution and Logistics Management*, 39, 6, 506–528.

Kowalski-Traklofer, K.M., Vaught, C., and Scharf, T. (2003) Judgment and Decision Making Under Stress: An Overview for Emergency Managers, *International Journal of Emergency Management*, 1, 3, 278–289.

Kumar, S. and Havey, T. (2013) Before and After Disaster Strikes: A Relief Supply Chain Decision Support Framework, *International Journal of Production Economics*, 145, 2, 613–629.

Leiras, A., de Brito, I., Queiroz Perez, E., Bertazzo, T.R., and Tsugunobu Yoshida Yoshizaki, H. (2014) Literature Review of Humanitarian Logistics Research: Trends and Challenges, *Journal of Humanitarian Logistics and Supply Chain Management*, 4, 1, 95–130.

Lindell, M.K. (2013) Emergency Management, in Bobrowsky, P. (ed.) *Encyclopedia of Natural Hazards* (263–271), Springer, Dordrecht.

Ludwig, T., Reuter, C., and Pipek, V. (2015) Social Haystack: Dynamic Quality Assessment of Citizen-Generated Content During Emergencies, *ACM Transactions on Computer-Human Interaction*, 22, 4, paper 17.

Maitland, C., Tchouakeu, L.N., and Tapia, A.H. (2009) Information Management and Technology Issues Addressed by Humanitarian Relief Coordination Bodies, *Proceedings of the 6th International ISCRAM Conference*, Gothenburg.

Mehta, A.M., Bruns, A., and Newton, J. (2017) Trust, but Verify: Social Media Models for Disaster Management, *Disasters*, 41, 3, 549–565.

Meum, T. and Munkvold, B.E. (2013) Information Infrastructure for Crisis Response Coordination: A Study of Local Emergency Management in Norwegian Municipalities, *Proceedings of the 10th International ISCRAM Conference*. Baden-Baden.

Pettit, S. J. and Beresford, A.K.C. (2005) Emergency Relief Logistics: An Evaluation of Military, Non-Military and Composite Response Models, *International Journal of Logistics Research and Applications*, 8, 4, 313–331.

Reuter-Oppermann, M., van den Berg, P.L., and Vile, J.L. (2017) Logistics for Emergency Medical Service Systems, *Health Systems*, 6, 3, 187-208.

Saab, D.J., Maldonado, E., Orendovici, R., Tchouakeu, L.N., van Gorp, A., Zhao, K., Maitland, C., and Tapia, A.H. (2008) Building Global Bridges: Coordination Bodies for Improved Information Sharing Among Humanitarian Relief Agencies, *Proceedings of the 5th International ISCRAM Conference*, Washington, DC.

Sarcevic, A., Palen, L., White, J., Starbird, K., Bagdouri, M., and Anderson, K. (2012) 'Beacons of Hope' in Decentralized Coordination: Learning from On-The-Ground Medical Twitterers During the 2010 Haiti Earthquake, *Proceedings of the CSCW '12* (47–56), Seattle, WA.

St. Denis, L.A., Palen, L., and Anderson, K.M. (2014) Mastering Social Media: An Analysis of Jefferson County's Communications During the 2013 Colorado Floods, *Proceedings of the 11th International ISCRAM Conference*, University Park, PA.

Starr, M.S. and van Wassenhove, L.N. (2014) Introduction to the Special Issue on Humanitarian Operations and Crisis Management, *Production and Operations Management*, 23, 6, 925-937.

Steins, K., Matinrad, N., and Granberg, T.A. (2019) Forecasting the Demand for Emergency Medical Services, *Proceedings of the 52nd Hawaii International Conference on System Sciences* (1855–1864), Grand Wailea, HI.

Swiss Re Institute. (2018) Natural Catastrophes and Man-Made Disasters in 2017: A Year of Record-Breaking Losses, *Sigma*, 1/2018.

Tapia, A.H. and Moore, K. (2014) Good Enough Is Good Enough: Overcoming Disaster Response Organizations' Slow Social Media Adoption, *Computer Supported Cooperative Work*, 23, 4–6, 483–512.

Thompson, S., Altay, N., Green III, W. G., & Lapetina, J. (2006) Improving Disaster Response Efforts with Decision Support Systems, *International Journal of Emergency Management*, 3, 4, 250–263.

Turoff, M. (2002) Past and Future Emergency Response Information Systems, *Communications of the ACM*, 45, 4, 29–32.

Vakkari, P. (1999) Task Complexity, Problem Structure and Information Actions: Integrating Studies on Information Seeking and Retrieval, *Information Processing and Management*, 35, 6, 819–837.

van Borkulo, E., Scholten, H.J., Zlatanova, S., and van den Brink, A. (2005) Decision Making in Response and Relief Phases, in van Oosterom, P., Zlatanova, S., and Fendel, E.M. (eds.) *Geo-Information for Disaster Management: Late Papers* (47–54), Springer, Berlin.

van Essen, J.T., Hurink, J.L., Nickel, S., and Reuter, M. (2013) Models for Ambulance Planning on the Strategic and the Tactical Level, *Technical Report*, Beta Research School for Operations Management and Logistics.

van Gorp, A F., Pogrebnyakov, N., and Maldonado, E.A. (2015) Just Keep Tweeting: Emergency Responder's Social Media Use Before and During Emergencies, *ECIS 2015 Research Papers* (paper 191), Münster.

van Wassenhove, L.N. (2006) Humanitarian Aid Logistics: Supply Chain Management in High Gear, *Journal of the Operational Research Society*, 57, 5, 475–489.

Wallemacq, P. and House, R. (2018) Economic Losses, Poverty & Disasters: 1998-2017, United Nations Office for Disaster Risk Reduction and Centre for Research on the Epidemology of Disasters.

Yates, D. and Paquette, S. (2011) Emergency Knowledge Management and Social Media Technologies: A Case Study of the 2010 Haiti Earthquake, *International Journal of Information Management*, 31, 1, 6–13.

Zhang, D., Zhou, L., and Nunamaker Jr., J.F. (2002) A Knowledge Management Framework for the Support of Decision Making in Humanitarian Assistance / Disaster Relief, *Knowledge and Information Systems*, 4, 3, 370–385.

Track 5.

Intelligent and Semantic Web Systems

Chairs

Julie Dugdale, *University Grenoble Alps, France*

Fiona McNeill, *Heriot-Watt University, UK*

Francisco José Quesada Real, *University of Edinburgh, UK*

Hemant Purohit, *George Mason University, USA*

Sharing Gut Feelings to Support Collaborative Decision Making

Frâncila Weidt Neiva
Universidade Federal do Rio de Janeiro
fran.weidt@ppgi.ufrj.br

Marcos R. S. Borges
Universidade Federal do Rio de Janeiro
mborges@ppgi.ufrj.br

ABSTRACT

Expertise-based intuition plays a key role in decision making, especially in complex environments as those involved with crisis and emergency domains where decisions often need to be made on the basis of dynamic, incomplete, and/ or contradictory information. In such environments, a deliberative analysis is often impossible or inefficient. Using teams to make collaborative decisions in complex environments can bring benefits to organizations, but the complexity of supporting this scenario also increases. The present work proposes a solution based on graphs to support the sharing of the intuition rationale in teams aiming at an accelerated expertise. The development of the proposal is part of a methodological context of design science research. In this paper we report the execution of one of the expected cycles that explores the use of generated artifacts in practice that then produced insights for the proposed computational support.

Keywords

Knowledge sharing, intuitive teams, collaborative intuitions.

INTRODUCTION

Experts make decisions heavily based on intuition (Klein, 2013). Expertise-based intuition can be understood as the translation of experience into action and plays a key role in decision making, especially in complex situations such as crises and emergency environments (Salas et al., 2010). In emergency situations, experts perform complex decisions characterized by high risk, time pressure, dynamic environment, multiples actors involved, goals poorly defined, and problems badly structured (Quesada et al., 2017; Hutchins and Kendall, 2011; Orasanu and Connolly, 1993). In these environments, a deliberative analysis is often impossible or inefficient, for example, due to time constraints (Okoli et al., 2018). In contrast to deliberative analysis, intuition is based on the identification of subconscious patterns accessed very quickly by experts (Ross et al., 2004).

Considering that organizations are increasingly globalized and working in increasingly complex environments, collaborative teams gain strength and adopt different network models, with their members often distributed across the globe and possessing different expertise and cultural contexts. An organization should consider that experts eventually leave and take with them tacit knowledge. Considering that organizations should be prepared to face these risks, it is important that not only technical capabilities be shared but also the capability of intuitive decision making.Using teams to make collaborative decisions can bring benefits to organizations, but the complexity of management also increases compared to the use of a single individual. In teams, knowledge is not contained in just one individual, but sliced through several members. Often, collaborative teams perform better than individuals in both quality and quantity decision-making. During decision-making, collaborative teams can more easily parallel tasks and leverage the redundancy of team knowledge and enrichment provided by different views (Huang et al., 2014). The research question is: How to support collaborative decision making in complex environments through a computational solution regarding a perspective of expertise-based intuition? Imagine that an organization has to decide whether or how to send doctors to provide lifesaving medical care in a challenging area that suffered with a natural disaster such as the earthquake in Haiti that created a tremendous coordination challenge for the humanitarian relief agencies (Van de Walle and Dugdale, 2012). A team working in this organization, made up of members with different perspectives, should articulate the different intuitions about that agreement and then collaboratively make the decision.

In this way, this paper consider expert-based intuition a kind of knowledge that should be managed and shared. The expert making a decision based in intuition can be compared, for example, to the most swimmers that cannot explain, in coherent prose, how they manage to keep themselves afloat but, besides that, they might learn and teach to do so, or to a pianist that even while it may be difficult to pay attention to the music and the movements of his fingers at the same time, it does not exclude that the pianist, at another time, can give an account of how he was using his fingers (Schmidt, 2012, apud Harré, 1977).

As the work space has undergone intense changes in the last decades, the organizations have become more knowledge-based and the use of pervasive technologies have shaped the current cognitive complexity of work performed in organizations (Hoffman et al., 2013). As a consequence, the task of sharing expertise-based intuition from the experts has become even more complex. However, it is not feasible for organizations, especially in emergency domains, that sharing this expertise takes the same amount of time as the expert has acquired. In this way, it is essential to take the notion of knowledge sharing to other levels. Knowledge sharing should be accelerated within organizations and the consideration of the use of complex systems for this should be taken into account (Hoffman et al., 2013).

As argued in (de Carvalho et al., 2018) if one accepts that certain kinds of knowledge have different qualities (e.g. expertise-based intuition rationale), as discussed before with the swimmer or pianist examples, then methodologies for making it explicit and formal are needed. Collaborative decision making considering the use of expertise-based intuition is a new proposal that raises new challenges with regard to computer-supported cooperative work point of view. The main objective of this project is to propose and implement a computational solution to support collaborative decision making in complex domains through a perspective of intuition based on expertise.

The methodological approach followed to develop this proposal was the design science research (DSR) and an evaluation of the artifacts was conducted to gather insights and evidence in order to elicit requirements to the computational solution presented in this paper. Based on the evaluation results we proposed a solution based on graphs to support the sharing of the intuition rationale in teams aiming at an accelerated expertise. More discussion about the methodological approach and evaluation was conducted along the paper.

In the remainder of this paper, the next section presents works related to expertise, intuition and decision making. The Section entitled ‘Sharing Gut Feelings to Support Collaborative Decision Making’ describes and discusses artifacts designed to support expertise-based intuition sharing. In the Research Model Section, an experiment to explore the artifacts feasibility and gather new insights is presented. Then, in the following Section a graph based solution developed considering the insights and data collected in the experiment is proposed. The final section concludes the paper and recommends directions for future work.

RELATED WORK

The literature provides some strategies to deal with the management of a decision making process (Orasanu and Connolly, 1993; Klein, 2004), and most of them can be applied to complex decisions. However, to execute these strategies it is necessary time and available resources that are not ever possible in an emergency scenario (Quesada et al., 2017; França et al., 2017). In this sense, expertise-based intuition has been identified as an important factor to decision-making in researches conducted with military, police, firefighters, doctors (Klein, 2004). Intuition is based on the identification of subconscious patterns (Adolph and Kretch, 2015; Ross et al., 2004). When experts make intuitive decisions, these patterns are accessed very quickly, unconsciously.

In this paper, intuition is considered a mental faculty (van Riel and Horváth, 2014) that can be measured and developed. Intuition can be used for different purposes and in different contexts. There is a consensus that it is an important result of experiential knowledge. The quality of people's intuitive judgment can be as good as the experience upon which it was built. In this way, expertise-based intuition can be defined as experience translated into action (Adolph and Kretch, 2015).

In a general sense, as stated in (Okoli et al., 2016), intuition is fast and requires unconscious processing of information (minimal mental effort). Intuition is alogical (i.e. neither contradicts nor follows the rules of logic) and the intuitive process involves tacit knowledge (i.e. intuitors find it difficult to describe how they arrived at their judgment). The outcome is holistic and information is processed based on the analysis of unconnected elements that are integrated to generate more meaningful insights (Okoli et al., 2016).

The model proposed in (Nonaka and Takeuchi, 1995) discusses the way knowledge is created, transferred, enriched and incorporated into organizational processes. For (Nonaka and Takeuchi, 1995) the existing knowledge in organizations can be identified in two forms, explicit or tacit. These two forms of knowledge interact and in the dynamic processes of organizations are transformed.

The Recognition-Primed Decision (RPD) model (Ross et al., 2004) was constructed based on observations made by decision-makers in operational situations. The RPD describes how decision-makers use pattern recognition to achieve decision objectives. For the recognition of patterns, the model considers four aspects, the goals to be achieved, the identified cues, that is, the identified pieces of segmented information, the expectations to be met and, finally, the actions to be taken. The RPD foresees in its structure the resources of situation awareness in order to generate a common plan of action and the use of mental simulation to predict and evaluate the strategy that will be covered in the decision. There are evidences that this model works well in complex situations, for example in conditions with time pressure and scattered information.

It is important to state that as discussed in (Schmidt, 2012), the term 'tacit knowledge' has been used, in a way that we also do not stand for, as a way for vaguely talking about practical knowledge as intuition, insights, heuristics, procedures, etc. The studies conducted by (de Carvalho et al., 2018) indicate that much so-called 'tacit' knowledge is not tacit at all and is regularly articulated in conversation or manifested in gesture, glance, gaze and so on.

In this sense, as (Graham 1964, pp. 137 f.) asked rhetorically, is it not possible to have an 'irrationally-arrived-at solution to a rationally-posed problem?', to which he replied himself: 'A concrete "guess" is an unconscious continuation of a conscious process'. We agree with (Schmidt, 2012) that the more experiments and computations the scientist makes, the more likely his 'intuition' is to be correct. In other words, through the conscious planning of experiments the accuracy of 'intuition' will be sharpened (Graham 1964, pp. 137 f.). In other words, experiences will build the subconscious patterns where expertise-based intuition relies on and different stimulus as new data will allow the improvement of patterns and also the trigger of these same patterns.

There is a growing interest in the area of intuition. Some recent research has been concerned with tackling the challenges of this area by developing frameworks, models and heuristics that deal with intuition (Hoffrage and Marewski, 2015; Okoli et al., 2016). However, to the best of our knowledge there is no study in literature that proposes a collaborative strategy to accelerate expertise focusing in intuitive teams.

SHARING GUT FEELINGS TO SUPPORT COLLABORATIVE DECISION MAKING

The methodological approach considered for the development of this research is the Design Science (DS). The DS methodology aims to produce knowledge about how to design (Dresh et al., 2015). Hevner et al. (2004) argued that the DS seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts, including constructs, models, methods, and so on. Such new and innovative artifacts create new reality, rather than explaining existing reality or helping to make sense of it (Iivari and Venable, 2009). The application of this methodology is not intended to seek optimal results, but rather results that satisfy the problem addressed in the research. Research based on DS proposes solutions to practical problems and also contributes to the improvement of theories.

In our research we conducted three cycles using DS. Cycle I provides the development of the general idea of how to share the expertise between an expert and a team (Neiva and Borges, 2017) (Neiva et al., 2017). Our theory was defined through the cycle I and can be stated as that expertise-based intuition can be shared and as consequence the expertise is accelerated. To explore the theory, cycle II produced the following artifacts: a macro process based on models of intuition and knowledge sharing and an initial model to support the use of intuition in decision making considering collaborative teams (Neiva et al., 2018) and (Neiva and Borges, 2018). This paper presents the conduction of cycle III where it was expected to gather evidences through an evaluation process investigating the artifacts generated in cycle II regarding practices of work. Considering the evidences, we suggested the development of an expertise sharing system to support expertise-based intuition sharing from an expert to a collaborative team in order to accelerate expertise.

The approach presented in (Neiva and Borges, 2017) and (Neiva et al., 2017) consists of splitting the expert's knowledge and transferring it to a team parallelizing part of the process, thus potentially saving time. This approach was the result of our initial investigation considering the expertise sharing field. We realized that existing techniques to replace and/or train a new expert are not fast enough, especially for those organizations operating in critical areas.

Given that experts apply intuition to multiple actions, a central issue in the approach presented in (Neiva and Borges, 2017) and (Neiva et al., 2017) concerns the development of a similar intuition rationale by the team. In this way, the team should work collaboratively and intuitively to obtain results analogous to those of the individual expert when acting within the organization. In this way, representing the cycle II in the application of the DS methodology in our research, our paper (Neiva et al., 2018) and (Neiva and Borges, 2018) presented a macro process to support the development of intuition in collaborative teams (Figure 1) and a model to support collaborative intuitive decision making (Figure 2). The macro process was built from the combination of the

knowledge transfer/creation model proposed by (Nonaka and Takeuchi, 1995) and the conceptualization of intuition as a mental faculty (van Riel and Horváth, 2014). The model, called Collaborative Recognition-Primed Decision Making, was built as an adaptation of the model presented in (Ross et al., 2004) for work explicitly with teams making collaborative decisions. The artifacts generated in cycle II was evaluated through a proof of concept (Neiva et al., 2018).

In a briefly overview of the macro process (Figure 1), the tables with decision requirements are inputs into the first stage of the transfer process, which is Socialization. In Socialization a defined (sub-) process promotes the discovery of patterns. During Externalization, the patterns identified and discussed with the team are documented and stored forming the initial subsidies for the construction of a collective mental scheme. In the Combination stage, the team works in conjunction with the expert on the construction of decisions based on intuition. At this point, the expert individual is "part of the team". The team organizes the intuitive decision-making guided by the model represented in (Figure 2). The constant feedback from the expert supports the update of patterns used as triggers for intuition. In Internalization stage, the team internalizes the established patterns by being exposed to the accomplishment of environmental tasks. In this stage, the expert is no longer a "part of the team", he/she tries not to intervene during the decision making, conducting a discussion session only after the decision is made. After the completion of a first round of the process, a new one may begin by considering a new level as a starting point.

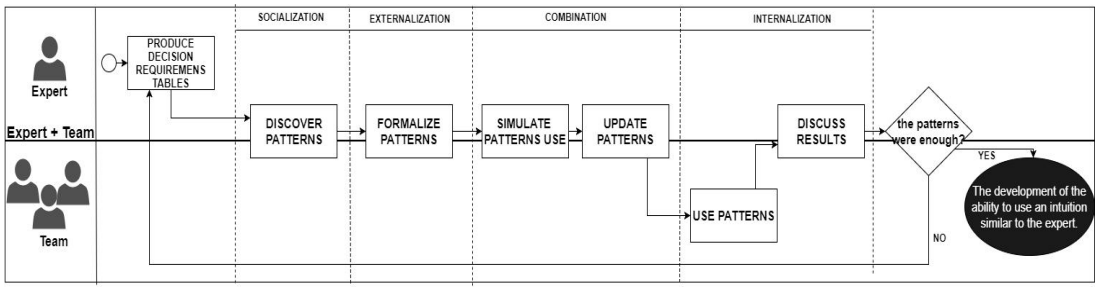


Figure 1. A macro process of expertise-based intuition sharing

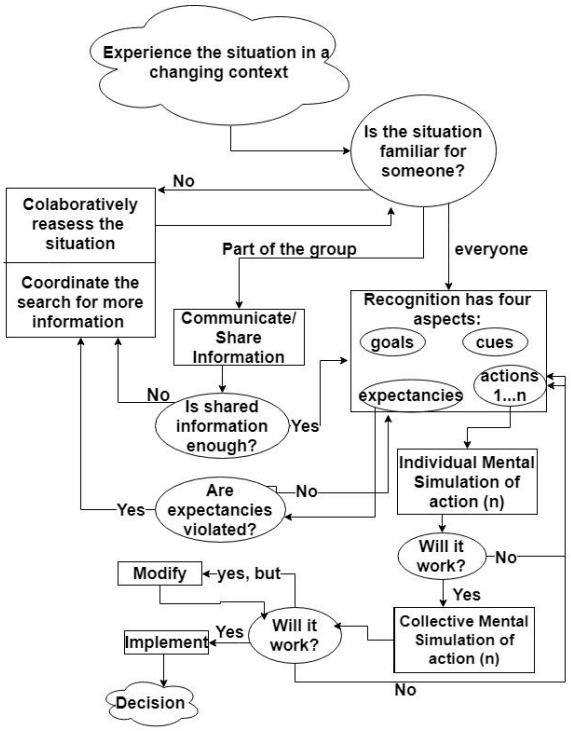


Figure 2. Collaborative Recognition-Primed Decision Making

The expected output of the process is the development within the team of an intuition capability similar to the expert's capability regarding the domain explored. For a more detailed explanation of the proposed artifacts, see (Neiva et al., 2018).

RESEARCH MODEL

The analysis of the artifacts was conducted considering a task where the expert-based intuition was shared using the artifacts. We imagine that the proposed artifacts have the potential to support an accelerated expertise by sharing the expertise-based intuition from an expert to a collaborative team. As a collateral effect the use of teams brings more resilience to organizations in the sense of knowledge sharing as discussed in the introduction section. Considering the proposed artifacts, the experiment aimed (i) to investigate their applicability in supporting the expertise-based intuition sharing and, (ii) to investigate if the artifacts contributed to the organization's work practice, also searching for strengths and weaknesses in them (iii) gather subsidies to generate insights about the evolution of the proposed artifacts.

In this way, the evaluation scope was defined based on GQM method (van Solingen et al., 2002) as following: **Analyze** the macro process of expertise-based intuition sharing and the collaborative recognition-primed decision making model **for the purpose of** evaluation **with respect to** behavioral, subjective, and performance dimensions **from the point of view of** experts and novices when performing decision-making tasks **in the context of** sharing expertise-based intuition.

The experiment was conducted in an organization that has dozens of courses in Higher Education. The organization is a public company with more than 500 thousand students. It is a dynamic company, constantly changing and improving its operations. Despite the organization does not belong to the emergency field, it is a complex organization, with a great capillarity, being present in 401 cities around the country. In this sense, by having this experiment being conducted in this organization, it was possible to gather evidence in order to mature the artifacts before exploring them in environments where the risks are higher, for example, those one involving the risk of losing human lives as presented in (Van de Walle and Dugdale, 2012). By being a public company, shareholders are an important factor to consider and the oscillations of the stock market also impact on decision making process that have to be agile and have impact in a great number of people, directly and indirectly. In a scenario of constant expansion and organizational changes, it is important to disseminate activities that support the decision making. A recurring and also vital task for the quality of the courses is the hiring of professors. In this sense, the experiment considered to support this task. For the hiring we had the participation of the coordinators of 4 different courses. The rules used for the hiring were the same defined by public notices in the organizational communication channels. It was possible that at the end of the hiring process it could be decided that no one would be hired. With the application of the task, the observer collected evidence indicating whether or not the decision was made using a rationale similar to the experts, in this case coordinators.

The experiment was divided into: Part 0 - The presentation of the Term of Free and Informed Consent. Only those who agreed and signed the term participated in the experiment. Part 1 - The definition of groups. Part 2 - Planning and design. Part 3 - Application of a follow-up interview.

Took part in this experiment 4 teams with 3 people. Each team consisted of 1 expert in the decision making process proposed by the task and 2 novices. The two novices were professors from the same work field who were interested in the coordinator position.

The team followed the proposed process and model to share the expertise-based intuition from the coordinators to the professors. One iteration in the process was made. To do this, before the experiment begins the organizer presented the objectives and operation of the experiment in a shortly briefing (about 15 minutes). The final outcome of the proposed experiment was the analysis of the similarity of novices and experts rationale regarding the related decision making.

Results

The results were divided into behavioral, subjective, and performance dimensions.

Regarding the **behavioral dimension,** through observations some insights were generated. It was observed that the patterns had different priorities, different weights regarding the decision that should be made. This became clear when we recorded in different groups, the novices questioned the experts about which indicators were more important in comparison with others. Also, during the use of patterns in the combination and internalization stages, it was observed that it would be important the use of a scale to express how much a pattern had been satisfied. We elicited this need by observing in our records that in different moments when the

groups were trying to make a decision, they realized that the satisfaction of the patterns was not a binary value, but rather, there were situations in which they were more or less satisfied.

The experiment made evident the prominence of patterns throughout the process of sharing intuition. It also showed that a pattern may have a qualitative feature but that it can be detailed to arrive at sub-patterns with more objective and measurable characteristics. We observed in our records that in different moments when an expert pointed out one of the patterns that he analyze in the decision making, if this pattern was not objective enough, the novices asked 'how to' analyzed it, and the answered always resulted in the decomposition of the original pattern.

Regarding the **subjective dimension,** all the participants were asked about what was their general opinion about the approach used to support decision making in this type of task, what are the strengths and weaknesses of the artifacts and what were their suggestions of improvement.

The coordinators informed that artifacts in their opinion were useful and supported the sharing of their rationale. They stated that the main advantage was to allow novices to make better decisions in real life situations without the need to have years of practice to take them. And for better or for worse, the team formed with the proposed artifacts would have the same characteristics as theirs. The novices stated that it was useful because they had access to the other novice's questions, in this way it was possible to expand the data for decision making. They also said that it is interesting because at the same time that they performed the task of decision making, they received instructions on how to improve their performance in this type of task by those who already have more practice. Regarding the use of teams, they stated that collaboration between different individuals is always beneficial because each one's abilities complement each other and doubts are solved more quickly. As a strong point they highlighted that the artifacts allowed them to expand their ability to analyze several points that only an expert would have. As weaknesses they pointed out that in some cases, a new way of resolving the task can be left out, once the novices deems it unnecessary as it is not considered by the expert. In this way, in some cases it can cause the non evolution of the decision making process because it will always follow the expert's rationale. They also indicated the difficulty in putting their own criteria aside. As suggestion of improvement they stated that there was a lack of representation formality of the patterns and also the lack of a support tool to consolidate all the gathered data. They also suggested that more than one expert could participate because in the process of making decisions, personal opinion may interfere. So they believe that having the vision of more experts, the patterns considered would be broader and more impartial.

Finally, regarding the **performance dimension,** at the end of the process, the 4 novices teams (professors) ended up made the same decision as the expert (coordinator).

Considering the results presented in behavioral, subjective and performance dimensions, our evidences pointed to that the expertise-based intuition from the expert was shared with the team regarding the decision-making task. The collected data generated evidence to accept our alternative hypothesis (H1). Revisiting the objectives of this experiment, the use of the proposed artifacts in a real scenario generated initial evidences about its viability addressing the objective (i). Even in a short period, there was evidence that the team was able to develop and use a rationale equivalent to the expert for the proposed task addressing the objective (ii) and also, the gathered subsidies generated insights about the evolution of the proposed artifacts that are explored in the following section, addressing the objective (iii).

GRAPH BASED SOLUTION

Based in the subsidies generated through the experiment, we have some insights to evolve the artifacts. Once the patterns proved to be the core of the role sharing expertise-based intuition process and it was observed that a better representation (not in natural language) in conjunction with a intelligent tool to manage the patterns is missing, this section explores a potential path to address these elicited requirements. In other words, we explore how to computationally support the sharing of expertise-based intuition rationale.

Pattern recognition enables the expertise-based intuition to emerge (Ross et al., 2004). In a simplified way, we can say that experts have a repertoire of patterns stored in mind and pattern recognition is a cognitive process that matches information received with a retrieved stored pattern. According to the Recognition Primed Decision (RPD) model (Ross et al., 2004) patterns are relationships between the most important cues that in conjugation generate an expectancy linked to a goal, which suggests a certain action.

It is possible to represent this situation as a graph. In this graph the nodes represent the important cues (C1, C2 ...) for a given expectancy be satisfied (E1). As observed during the conducted experiment, cues do not have the same weight to address an expectancy. In other words, some cues are more important than others. Figure 3 represents the pattern as an oriented graph with edge weights.

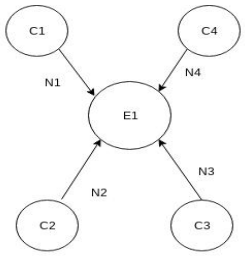


Figure 3. Stored Pattern Representation

The structure can become more and more complex, for example, we can have cues that are associated with more than one expectancy, with edge weights to each relation. Or also a pattern having other patterns in its composition being expressed by an expectancy linked to other expectations. Even more, we can have more cues merging in a bigger cue (Figure 4) transforming itself in an new expectancy or even a cue being broken down into sub-cues .

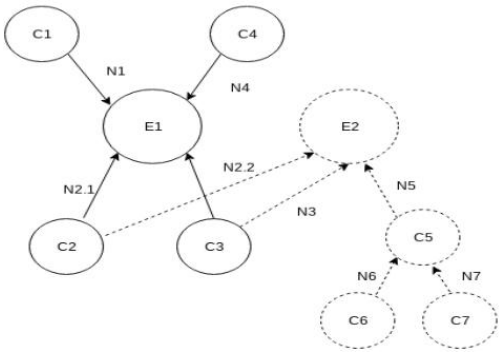


Figure 4. Patterns associations.

Evolving the structure and also using an analogy, the cues can be compared with filters that receive information from the environment and let only the chunks of information related to a certain cue passing. Information flows through the structure as resources flowing through pipes, each pipe with its own capacity, from a source to a sink (destination). In Figure 5, it is possible to notice new things, such as node A that represents the environment from which all the information is retrieved, We can also notice (N, M) pairs at the edges that connect the nodes, respectively representing the maximum flow rate and the incoming flow. In the context of this research, the incoming flow is how much a cue was perceived in relation to the weight (maximum flow) of this cue regarding an expectancy. We have also represented in Figure 5, the expectancy E linked to a goal G, which suggests a certain action depending on how much flow has reached the G node (sink).

This structure can also become more and more complex, for example, we can have more than one expectancy associated with a goal and also the same expectancy associated with more than one goal. Once the graph is built, the collaborative team can use it. Also, there is a possibility of each member of the team work focusing on be aware of one cue or part of the cues that are linked to a certain expectancy.

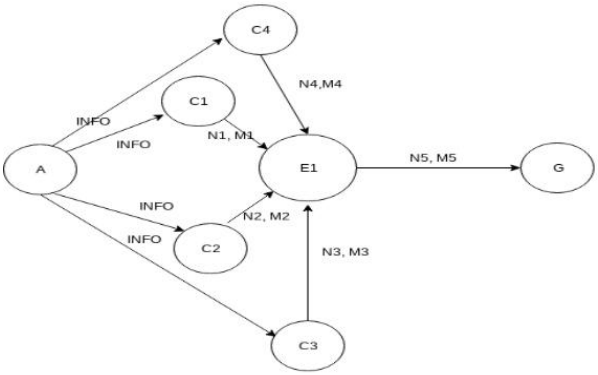


Figure 5. Decision-making support graph

This new artifact open new possibilities to the sharing expertise-based intuition research. Once we treat expert-based intuition as a form of knowledge, the graph based solution are a possible path to support the management of the complexity presented in sharing it, and also, enables the translation of unstructured data into a structured for of actionable knowledge for decision support. As claimed by the novices during the experiment, this new artifact allows the construction of the graphs using more than one expert. Furthermore, it is possible to explore the use of the wisdom of the crows (Chocron et al., 2016) in the construction of the graphs to promote the sharing of the expertise-based intuition. Besides that, it allows a more collaborative work by sharing a common structure among the participants.

CONCLUSIONS

In this paper we presented an experiment to analyze behaviors, subjective experience, and performance outcomes regarding the use of artifacts to enable sharing expertise-based intuition to support the decision-making process in complex environments. Our experiment generated evidence about the artifacts feasibility, as well their value to contribute the practices of work regarding expertise sharing activities.

This work was mainly motivated by the lack of studies in literature investigating how sharing expertise based-intuition can be explored to promote an accelerated expertise and also, a more resilient collaborative setup. Regarded this lack of studies, we conducted this work following the design science research methodology. The application of this methodology is not intended to seek optimal results, but rather results that satisfy the problem addressed, contribute to solutions to practical problems, the improvement of theories and understanding of a certain research field. Our theory is that expertise-based intuition can be shared and as consequence the expertise is accelerated. To work in this theory we designed artifacts to perform the sharing and experimented them in decision making practices. The insights generated in the experiment allowed the development of graph based solution to represent and manage the patterns used in the intuitive decision-making.

This experimental study presented some limitations. During the experiment, the participants knowledge on collaboration tasks proposed may influence the outcomes. In order to reduce this threat, a characterization questionnaire was used to select participants. The low number of participants does not allow generalizing results obtained. Nevertheless, this paper presents important contributions, new insights and increases the scarce body of knowledge of this research field.

As future works, the conduction of experiments with larger subjects sample and considering different complex environments can generate contributions to allow generalizing results obtained in this paper. Furthermore, we are planning the conduction of a new DSR cycle to explore and evolve the new artifact proposed, namely, the graph based solution.

ACKNOWLEDGMENTS

We thank CAPES and FAPERJ that supported this work and also thank the participants in the experiment for their patience and cooperation. The work of Marcos R. S. Borges has been supported by FAPERJ under grant # E-26/202.876/2018.

REFERENCES

Adolph, K.E. and Kretch, K.S. (2015). Gibson's theory of perceptual learning. International Encyclopedia of the Social and Behavioral Sciences, 10, 127-134.

Chocron, P., Gromann, D. & Quesada, F.J. (2016), Towards Building Ontologies with the Wisdom of the Crowd. in Proceedings of Diversity @ ECAI 2016 International Workshop on Diversity-Aware Artificial Intelligence. pp. 1-11, 1st International Workshop on Diversity-Aware Artificial Intelligence , The Hague, Netherlands

de Carvalho, A. F. P., Hoffmann, S., Abele, D., Schweitzer, M., Tolmie, P., Randall, D., & Wulf, V. (2018). Of Embodied Action and Sensors: Knowledge and Expertise Sharing in Industrial Set-Up. *Computer Supported Cooperative Work (CSCW)*, *27*(3-6), 875-916.

França, J. B. S.; Neiva, F. W.; Dias, A. F. S.; Borges, M. R. S. (2017) Towards Projected Impacts on Emergency Domains Through a Conceptual Framework. In: International Conference on Information Systems for Crisis Response and Management, 2017, Albi, France. XIV International Conference on Information Systems for Crisis Response and Management, 2017.

Graham, Loren R. (1964). Bukharin and the planning of science Russian Review, vol. 23, no. 2, April 1964, pp. 135–148.

Harré, Rom (1977). The structure of tacit knowledge, Journal of the Society for Phenomenology, vol. 8, no. 3,

October 1977, pp. 172–179.

Hevner, A.R., March, S.T., Park, J. and Ram, S. (2004). Design science in information systems research, MIS Quarterly, 28(1), 75-105

Hoffman, R. R., Ward, P., Feltovich, P. J., DiBello, L., Fiore, S. M., & Andrews, D. H. (2013). Accelerated expertise: Training for high proficiency in a complex world. Psychology Press.

Hoffrage, U. and Marewski, J.N., (2015). Unveiling the Lady in Black: Modeling and aiding intuition.

Huang,H. C., Davy, F. L. Shih, H. Y. and Fan, C. J. (2014). "Accelerating Knowledge Adoption: Information Systems Change Management?" in Approaches and Processes for Managing the Economics of Information Systems 2014 pp. 253.

Hutchins, S., Kendall, T. (2011) The Role of Cognition in Team Collaboration During Complex Problem Solving. In: Mosier, K.L., Fisher, U.M. (eds). Informed by Knowledge Expert Performance in Complex Situations. Psychology Press, Taylor & Francis Group, p. 69-90.

Iivari, J. and Venable, J. (2009, June). Action research and design science research-Seemingly similar but decisively dissimilar. In *ECIS* (pp. 1642-1653).

Klein, G.A., (2004). The power of intuition: How to use your gut feelings to make better decisions at work. Crown Business.

Klein, Gary. (2013). Seeing what others don't: The remarkable ways we gain insights. Public Affairs.

Nonaka, I. and Takeuchi, H. (1995). The knowledge-creating company: How Japanese companies create the dynamics of innovation. Oxford university press.

Okoli, J.O, Weller G., and Watt, J. (2016). Information processing and intuitive decision-making on the fireground: towards a model of expert intuition. Cogn. Technol. Work 18, 1 (February 2016), 89-103.

Orasanu, J., Connolly, T. (1993) The Reinvention of Decision Making. In: Klein, G.A., Orasanu, J., Calderwood, R., Zsambok, E. (eds), Decision Making in action: Models and Methods, New Jersey: Ablex Publishing Corporation Norwood, p. 3-20.

Quesada, F.J., McNeill, F., Bella, G. & Bundy, A. (2017). Improving Dynamic Information Exchange in Emergency Response Scenarios. in Proceedings of 14th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2017). France, 14th International Conference on Information Systems for Crisis Response and Management, Albi, France.

Neiva, F. W., França, J. B., Dias, A. F., & Borges, M. R. (2018). Agnosco: Transferring Intuition from Individuals to Collaborative Teams. In press: Computer Supported Cooperative Work in Design (CSCWD).

Neiva, F.W. & Borges, M.R. (2017), April. Split expertise transfer: An innovative collaborative approach to support accelerated expertise transfer. Computer Supported Cooperative Work in Design (CSCWD), 2017 IEEE 21st International Conference on, pp. 48-53.

Neiva, F. W., França, J. B., Dias, A. F., & Borges, M. R. (2017, October). An innovative approach to accelerate expertise transfer in organizations. In Systems, Man, and Cybernetics (SMC), 2017 IEEE International Conference on, pp. 1770-1775.

Neiva, F. W. & Borges, M.R. (2018). What is the basis for your guesses? Tell us! Sharing Expertise-Based Intuition. In Proceedings of 16th European Conference on Computer-Supported Cooperative Work-Doctoral Colloquium. European Society for Socially Embedded Technologies (EUSSET).

Ross, K.G., Klein, G.A., Thunholm, P., Schmitt, J.F. and Baxter, H.C. (2004). The recognition-primed decision model. ARMY COMBINED ARMS CENTER FORT LEAVENWORTH KS MILITARY REVIEW.

Salas, E., Rosen, M.A. and DiazGranados, D. (2010). Expertise-based intuition and decision making in organizations. Journal of management, 36(4), 941-973.

Schmidt, K. (2012). The trouble with 'tacit knowledge'. *Computer supported cooperative work (CSCW)*, *21*(2-3), 163-225.

Van de Walle, B., & Dugdale, J. (2012). Information management and humanitarian relief coordination: findings from the Haiti earthquake response. *International Journal of Business Continuity and Risk Management*, *3*(4), 278-305.

van Riel, A.C. and Horváth, C., (2014). Conceptualizing intuition as a mental faculty: Toward a 'critique of intuitive reason' and a process model of intuition. Handbook of Research Methods on Intuition, edited by M. Sinclair, pp.42-67.

van Solingen R., Basili V., Caldiera G., Rombach H.D. (2002). Goal question metric (gqm) approach. In: Encyclopedia of software engineering.

How to build an innovative C2 system supporting individual-centric emergency needs?

Guillaume LAMBERT
French ministry of interior
guillaume.lambert@interieur.gouv.fr

Bruno FONTAINE
ToMCo
bfontaine@tomco.fr

Michel MONNERET
Civil Security Digital Agency
michel.monneret@interieur.gouv.fr

Rafai Mourad MADANI
French ministry of interior
rafai-mourad.madani@interieur.gouv.fr

ABSTRACT

The paper describes the need for, and work in progress to provide the French population with a modern emergency communication infrastructure that uses open source components to deliver real time communications from smart phones as well as traditional routes.

The article puts forward the vision of the NexSIS 18-112 project aimed at designing and implementing the next generation AI enhanced emergency services response platform for France. The vision and ambition of the NexSIS 18-112 system is to rewrite the command and control system from scratch at a national level, providing it with state of the art functionalities.

Anticipating the future deployment of 5G networks, the work described in the article explains how to ensure the transition of the legacy emergency operation systems to an operational IP-based model, capable of offering voice, video, Instant Messaging, and Real Time Text (RTT) services to emergency services' operators.

Keywords
Emergency services, digital platform, personalization, individual centric, virtualization, cloud, emergency hub, AI, unified communication, IoT, SIP/RTP, NG112, ESInet.

INTRODUCTION

As Tom Wheeler, former chairman of the American Federal Communications Commission, pointed out in 2015, our emergency response systems face an emergency of their own in the form of outdated technology. Simply put, the communications technology behind the emergency response system is dangerously out of date. Currently, the French PSAP (Public Safety Answering Points) handle about 18 million calls a year, an increasing number of them from cellphones.

But these PSAP can't receive any data such as real time location, text, photo or video from a person in need — capabilities that are considered commonplace for any European citizen with a smartphone. Similarly, the generalization of connected objects is a new challenge for emergency services.

The future deployment of 5G networks will have considerable implications for the emergency communications sector. The increased performance of the 5G wireless and mobile networks, the enhanced security and the improved device-to-device communications will open a realm of new possibilities, which have the potential to greatly improve emergency responses and ultimately save more lives.

Faced with this situation, the French government has taken the decision to revolutionize the organization of emergency call processing to make the most of the capabilities of mobile phones and other connected device. Thanks to the NexSIS 18-112 project, the population and the emergency services will move into the era of data and online services.

The incredible new functionalities offered by the information technology (integrated communication, cloud, web, social networks, mobile, Internet of Things…) are not used by traditional existing software solutions. Innovative solutions such as 112 mobile applications or social networks are emerging, but their integration in existing information systems is difficult and costly. The issue is how to replace these obsolete analog emergency response infrastructures that are ill-suited to the demands of a highly digital public.

New approaches, like cloud-based architecture or software defined architectures, are "cost killers" and provide an answer to the overall and growing cost of a multitude of different and local systems.

Public Safety Answering Points (PSAP) need to be equipped with the latest unified communication tools allowing rich and personalized exchanges between emergency services and distressed population. A simple photo or a short video brings an incredible amount of information if they can be taken and easily transmitted by the citizen to the PSAP, or from the first responder on the field to the operation center. For this, current telecommunication technologies based on telephony must be replaced by technologies based on IP networks.

Virtualization, allowing different PSAP to act individually but also collectively, is also included in the original specification of the project. Virtualization and multi-tenancy feature allow also to support complex and rapidly evolving organizations and provides an answer to more and more global, distributed, dispersed threats and attacks. This is a crucial improvement compared to the existing local, not inter-connected ICT systems.

NexSIS 18-112 is both an operational system dedicated to shortly replace all existing local solutions, and also an "online platform" able to exchange with third party platforms and citizen provided solutions (the "emergency hub"). AI and big data are also taken into account in the core design of the platform and the first releases will include AI algorithms to propose the most adequate answer to complex emergency situations.

THE CONTEXT OF CIVIL SECURITY FORCES IN FRANCE

Civil rescue forces include 250 000 firemen, 80% being volunteers and 20% professionals. 18 million calls are processed each year leading to 4,5 million operations. 3,6 million victims are taken in charge by rescue operations.

The organization is based upon a departmental approach (about 100), each department having a 112 Public Safety Answering Point managing both entering calls and rescue operations.

Today, each department has its own decentralized information system (hardware and software) managing entering emergency calls, operation management and crisis management.

The NexSIS 18-112 project is aimed at providing all Public Safety Answering Point (PSAP) organizations, located in France or overseas, with a complete set of common application services (ICT, CAD, C2, mobile application, etc.) based on SaaS (Software as a Service) mode allowing to fulfill each PSAP requirements but giving also a possibility to have a global view upon all the territory and to pool forces in case of complex emergency situations.

The use of innovative and advanced architecture and technologies, which have a strong and positive impact on existing PSAP operational practices, has led to the decision to set-up several PoC (Proof of Concept) to implement and validate both the technology feasibility and the new functionalities and organizations allowed by the technology. Three PoCs are running today, and the first operational PSAP to use NexSIS is planned end 2020. Among features already operational are the unified communication platform developed in the private cloud of the French ministry of interior, the core AI based mobilization algorithm, the multi-tenant data structure and API's. Those were chosen being considered as the most innovative and less risky for the project.

UNIFIED COMMUNICATIONS FOR NEXSIS 18-112

The words "unified communications" refer to different definitions. In the NexSIS 18-112 project, unified communications make reference to several concepts:

Using IP networks and normalized IP protocols

The unified communication module relies on the use of the pair of SIP and RTP protocols:
- RTP (Realtime Transport Protocol) allowing streaming media such as voice, video, messages and applications such as WebRTC, video conferencing, push-to-talk features
- and SIP (Session Initiation Protocol) which allows the initialization of a session between 2 or several users and then the exchange of voice, images, videos and data between them.

This concept is extensively used in NexSIS 18-112 through a SIP-based communication solution serving as an integrated engine to deliver emergency calls. Deployed in the private cloud of the French ministry of the interior, this application layer includes advanced routing and contact center features. It delivers a very scalable and intelligent Public Safety Answering Point (PSAP) communication platform able to receive signalization (SIP header and message body) of an incoming call, to locate the caller by different means, and to determine to which PSAP the call must be routed under sophisticated algorithms: for instance, suppose a PSAP is not able to receive and to process an incoming call for any reason, the call may be routed to another emergency service designed as a backup. If many calls arrive from a known location where has been detected an "event" (an important fire, a car accident), all incoming calls can be directed to a dedicated temporary crisis center… RTP enables the PSAP to receive and process multimedia emergency calls, to use location-based services to pinpoint the exact location of a caller, or to establish real-time visual assessment using the smartphone camera.

The "intelligence" and the "multimedia" aspects allowed by NexSIS IP communication platform are not limited to the incoming calls from the population but are also available for all security forces and for any device (PC, tablet, phone). They provide enhanced situational awareness. They leverage video and data to allow first responders to share live footage with the Public Safety Answering Point (PSAP), or with other public safety services. Any fireman can take a photo of a victim to ask support in a real time or to share with the operation center a real time video of a fire. This provides a much more accurate picture of an emergency situation, speeding up incident response times by using a multitude of potential data sources for incident command.

With a single platform connecting 100 PSAP and all the first responders sharing this platform, data fusion can be done, and applications shared among the public safety community.

A simple user interface available on a web browser

With no pre-installation on the PC, the user interface allows functionalities such as WebRTC phone, visual voicemail, contacts and presence, chat and messaging. Integration of unified communications within dedicated applications (like a 112 mobile application for the population, or field crisis management application for advanced command centers) are also made very easy whatever operating systems of the device.

An exclusive Open Source software approach

As seen before, all data streams and advanced routing features are controlled by software: there is no telecommunication dedicated hardware other than basic IP network device. The different software "bricks" come from different open source software communities such as Asterisk PBX (Asterisk community, *https://www.asterisk.org*) and Kamailio SIP server (Kamailio community, *https://www.kamailio.org/w/*). Wazo community (Wazo community: *http://wazo.community*) provides the integration and a full set of APIs allowing central applications to drive all communication events and flows. All software modules are installed in the (OpenStack based) private Cloud of the Ministry of the Interior. It is to notice that the communication software can request dynamically additional virtual machines using native OpenStack APIs (OpenStack community, *https://www.openstack.org*) to answer to unusual growth of calls, with no other limit than the number of physical servers of the Cloud: this functionality is very important knowing that NexSIS 18-112 has to serve all existing PSAPs of the territory and that national crisis event (like a tempest on the whole territory) can increase heavily the number of instantaneous calls (typically, 20 000 additional calls per hour).

INFRASTRUCTURE FOR NEXSIS 18-112

A dedicated innovative architecture

The main different elements of the infrastructure are the following:

- An NG112 compliant network, i.e an ESInet (Emergency Services IP network), that includes all the functions (BCF, ESRP, ECRF, LNG, LIS) for data transport, delivery and end-to-end connectivity between the requester, NexSIS applications in the Cloud, and local PSAP workstations.
- The RIE ("Réseau Interministériel de l'État") network which is an existing private and secure IP network dedicated to data exchange between State organizations.
- Remark: the ESInet MPLS network is able to exchange data flows (http) in case of RIE failure, and conversely, the RIE network can transport SIP and RTP fluxes in case of ESInet failure.
- The dual site of the Ministry of the Interior consists of two different cloud sites, where unified communication and NexSIS applications are hosted, in an "active/active" mode. The two sides are linked by a black fiber for fast exchanges and the access infrastructures of each side are secure and redundant. They are based on OpenStack open source software.

- A local Public Safety Answering Point (PSAP) infrastructure where local LAN is linked by two links to the ESInet and two attachments to the RIE. The local PSAP

infrastructure also include a local WAN network to connect all operation centers of the department (there are 7 000 local operation centers in France)

Besides above infrastructure components, the following principles apply for application architecture : a full WOA (Web Oriented Architecture), RESTful based, where a Single Page Application (SPA) (Angular community: https://angular.io) is executed in the browser of the workstation (or more generally, on a device) and makes request to application servers hosted in the cloud datacenters.

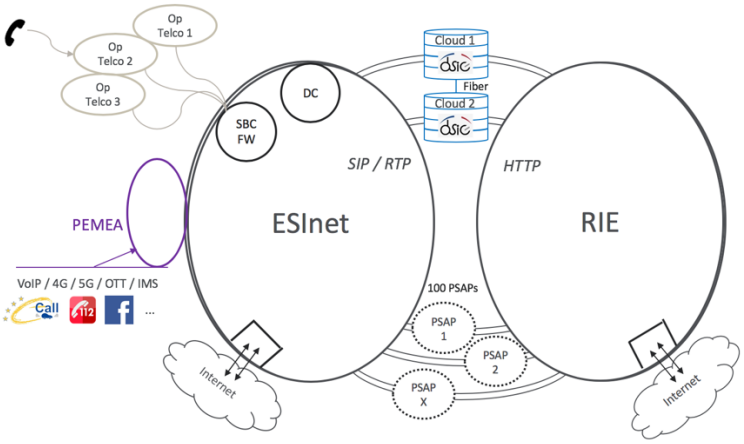


Figure 1. NexSIS 18-112 Infrastructure summary

In addition to the "rich" communication capacity with the population, the enormous advantage of this full IP and cloudified architecture is that it allows all Public Safety Answering Points (PSAP) to benefit from a set of webized services at the best of technology and responding to their needs. It also provides a common application environment for all operators greatly facilitating the mutual assistance or the resumption of activities between PSAP. Finally, it lays the necessary technical foundations for the development of software services focused on citizens in distress.

The support of individual-centric emergency needs

Technology brings new relationships between emergency services and the population. Building user centric information systems means taking full advantage of the potential offered by mobile internet and connected sensors.

The personalization of an emergency call is based at first on a precise localization of the requester: NexSIS 18-112 supports existing localization services provided by Telco's but supports also the emerging AML (Advanced Mobile Location) protocol being implemented in IOS and Android OS.

Getting the caller location before picking up the call allows a pre-processing of the request: for instance, if the location is a public building with dedicated and predefined security processes, or an already known "event" (big fire, flooding zone…), or the caller already identified by a previous call, the routing algorithm can apply rules and prepare the personalization of the exchange with the PSAP operator.

The use of a 112 mobile application is another means to implement individual-centric approach for emergency management.

Apps are key to a meaningful user-centric strategy, because they make it possible to fully exploit the data from the different sensors of mobile phones, thus providing valuable

information for a personalized support of distressed citizens. NexSIS 18-112 supports PEMEA architecture allowing citizens of other European countries to access French Public Safety Answering Point (PSAP) with their mobile and own specific Apps.

Along the same lines, public warning or private warning can be personalized in advance by the specific data entered by the requester, as it is the case in the framework of BE-ALERT platform (*http://be-alert.be*).

In addition to supporting the general public, these user-centered capabilities facilitate emergency communications by individuals with disabilities (e.g., persons who are deaf, deaf-blind, hard of hearing, or have a speech disability).

The growing role of IoT

The Internet of Things (IoT) envisions billions of objects connected to the Internet that continuously generate data about the physical environment. Thanks to the IoT, devices may initiate calls to 112 without human intervention. Data is presented to a call-taker with – or without – a human voice behind it. This is the impact that the Internet of Things will have on Emergency Services and the Public Safety arena. More and more emergency alerts are incoming by IoT devices. Taking into account this growing role of the Internet of Things in reporting emergency needs requires IP technologies and data exchange capabilities such as those offered by the NexSIS digital platform.

Thus, NexSIS 18-112 supports the e-Call service which is a European compulsory emergency system installed in all new vehicles. In case of accident, car sensors trigger an automatic emergency call and convey data to a dedicated call center in charge of handling and filtering those alarms. When confirmed, the alarm is transmitted to the proper 112 Public Safety Answering Point (PSAP) using dedicated APIs. Much information can be used to personalize the intervention, for instance the speed of the vehicle when the crash occurred and the type of the vehicle. This later information can be used to define which kind of tool kit has to be brought to process the extrication of the victims, reducing drastically rescue times and saving lives.

Fire-detectors alert transmission and support, automatic AI image processing of highways or city cameras to detect accidents, senior tele-assistance… are examples of new emergency devices able to increase personalization, especially when associated with pre-loaded data transmitted along with the alert itself.

NEXSIS 18-112, THE DIGITAL HUB OF EMERGENCY SERVICES

Citizens becoming part of the rescue process

Fueled by the explosion of social networks and propelled by an « open data » and API strategy, co-creation encourages the involvement of citizens in the execution of relief operations. More and more initiatives created by citizen communities allow a better identification of emergency needs. Dedicated applications allow to rapidly involve a first aid individual for the emergency support of the victim while waiting the emergency forces arrival. Several applications already exist such as “permis de sauver” (*http://permisdesauver.info*), “staying alive” (*http://www.stayingalive.org*), “qwidam” (*http://www.qwidam.com*).

The efficiency of those platforms will considerably grow when connected to NexSIS 18-112. For this reason, NexSIS 18-112 is built upon the concept of being the “Digital Emergency Hub” allowing connection between all the emergency requesters (citizen, other organizations, device…) and all the stakeholders involved in the response to the emergency needs.

NexSIS 18-112 front-end applications (call processing and routing the alert) and NexSIS back-end applications (mobilization, operation and crisis management) extensively uses the Digital Hub to communicate between themselves but also with other third parties and other forces platforms. The platform logic advocated by the architecture adopted in the framework of the NexSIS project makes it possible to give substance to the notion of open innovation. Indeed, the platform includes the exhibition of its data models as well as an API library allowing the private and citizen initiative to add services to those developed by the Ministry of the Interior.

The merger of social networks and IoT gives birth to the Social Internet of Things (SioT) concept. For instance, vehicles commuting from home to office can join a social network to share information (traffic congestion experience, accident warnings) with emergency services. This is why the NexSIS digital platform has developed the ability to receive information flows produced by the Waze social network and to edit information in the online maps produced by this application.

Finally, citizens can also be integrated in emergency management teams helping authorities in the VOST (Virtual Operations Support Team) context. It is the case of VISOV in France (*http://www.visov.org*) or CanVOST in Canada (*https://sites.google.com/site/vostcanada/*). The challenge is to integrate within the NexSIS crisis management modules the data from the VISOV action such as the collection of information published on the web and the edition of collaborative maps. The interconnection of NexSIS 18-112 and the VISOV platforms will drastically increase the efficiency of the cooperation between the official emergency agency and this social media based upon trusted agents.

The growing need to inter-operate with other forces

The decision has been taken in France to pool 112 call centers to provide a unique and professional identification and qualification of the request, and to transmit the alerts when properly qualified to the different concerned public safety forces (firefighters, police, urgent medical help). The digital emergency hub is designed to support all these exchanges between the different organization using mainly the EDXL (Emergency Data Exchange Language) messaging standard for this purpose.

NexSIS 18-112 Digital Hub is based upon a standardized set of APIs for real-time exchanges and also the use of the standard EDXL for inter-messaging needs. The Hub has its own directory to support intelligent routing of messages, and security features to assure a continuous service. This architecture model might provide a foundation for the development of cloud-based services for emergency services.

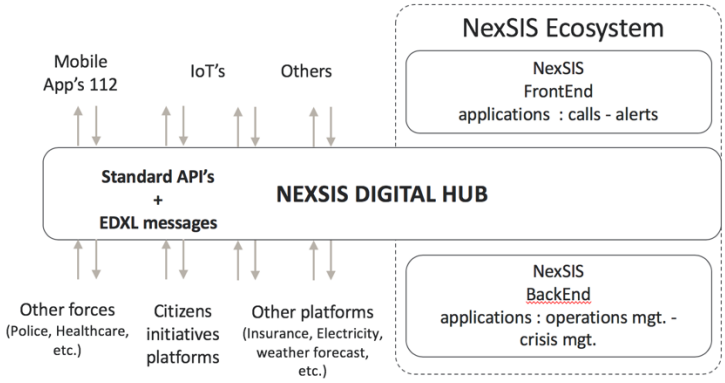


Figure 2. NexSIS 18-112 Digital Hub Principles

As an example, the digital Hub integrates the technical engine allowing to support the EDXL-DE (Distribution Element) which ensures message distribution. Another feature of the digital Hub is to offer several different formats of entities interchange such as JSON, SQL, mimeType, EDXL and even CVS and to allow format conversion.

HOW AI CAN IMPROVE IN ANSWERING CITIZEN NEEDS, PERSONALIZATION AND RESPONSE OPTIMIZATION

Finding the "best" answer to an emergency situation

Historically, the algorithms used to transform an emergency call to an operation, based upon available resources (vehicles, tools, and firemen), has been designed on simple principles like choosing generally the nearest operation center able to provide the resources needed. The algorithm for mobilizing and dispatching relief resources within NexSIS 18-112 is based on a more sophisticated approach that integrates some artificial intelligence tools such as expert systems (rules inference engine) (Business Rules Community: http://www.brcommunity.com) and optimization under constraints.

This architecture can take into account much more complex situation when dealing for instance with a major event where different constraints have to be taken into account in the decision process like the rapidity of intervention, but also the need to keep forces in back up, and the need to mobilize very specialized and scarce forces, the need to separate what is urgent and has to be done immediately and what can be done later on. Another advantage is the fact that "declarative programming" is much more powerful than procedural programming for this kind of application and can be externalized from the application itself, allowing to improve the algorithms without changing the application code.

This feature is actually under testing in a PoC to be available as soon as the first release.

NexSIS 18-112 will rapidly acquire an enormous amount of data, dealing with 18 million calls and 4,5 million operations each year. This offers a tremendous opportunity to apply deep learning to the existing AI based algorithms in a second phase.

Many dedicated AI applications in the NexSIS 18-112 roadmap

Besides this first application, several AI based opportunities have been identified during the specification phase:

- Call signals analysis

- Automatic translation capabilities to help processing foreign language calls
- Automatic detection of wrong or malicious calls
- In case of major crisis (terrorist attack, large flood), identification, extraction and diffusion to the authorities of the new and pertinent information often diluted in the massive information flow (flitering)
- Crisis analysis support and decision-making assistance
- Image analysis on the field
- Predictive analysis of emergency situation
- Linguistic analysis of social networks…

Another example of application is to detect in advance "non-nominal situations" like having several alerts over a large area with reports of a strong pain in the stomach. In that case, it could be an intoxication of people having the same meal several hours before.

Likewise, in the case of a global terrorist attack at different points of a city, AI could rapidly detect the "non-nominal" aspect of the situation and sends warning to the crisis center.

Those different opportunities will be evaluated during the year 2019 using POCs when needed and will be placed upon NexSIS18-112 roadmap of future releases.

QUALITY OF SERVICE AND SECURITY

NexSIS 18-112 being a common, unique, centralized system delivering its services to all Public Safety Answering Points (PSAP) in France, the questions of quality of service (QOS) and security become essential.

It is out of the scope of this paper to detail the different solutions to guarantee QOS and security, but it is possible to outline the major assumptions:

- QOS, and essentially the availability and the response time of the system for users, is guaranteed by the systematic use of modular growth (horizontal scalability) and fault tolerant capabilities which are natively offered in the Web Oriented Architecture (REST) coupled with cloud based hosting. Two different dedicated networks are used to link the cloud hosted application and the PSAP, each one is a backup of the other in case of failure. Administration and supervision tools are part of the original design to guarantee Service Level Measurement to be compliant with Service Level Agreement. NexSIS 18-122 is ITIL V3 2011 compliant.
- Cybersecurity measures designed to protect digital assets and network devices are essential to NexSIS 18-112. Two of the main infrastructure components upon which the project relies are already at a very high level of security:
    - the private cloud of the Ministry of interior is hosting the most sensitive applications of the French government,
    - the "RIE" network (ie an existing private and secure IP network dedicated to data exchange between State organizations), which is also highly protected from malicious attacks.
    - The ESInet design follows the recommendation described in the NENA_08-506_Emergency_Services_IP_Network_Design_12142011 document.

Each connection with an external link (Telco SIP Trunk, Mobile Apps APIs, PSAP…) is provided with defense modules adapted to each case and identified risks.

Besides, NexSIS 18-112 has to receive the Security Official Approval delivered by the independent National Digital Security Office before going live.

CONCLUSION

NexSIS 18-112 digital platform under construction has the ambition to take advantage of the latest technology innovation and research to build and deliver a whole set of new services both to the population and to the emergency agencies. The multi-tenant approach of NexSIS 18-112 allows new cooperation processes between emergency operation centers themselves, but also with other third parties involved in emergency situations such as citizens as well as other public safety forces and VOST organizations. NexSIS 18-112 makes possible real-time and immediate reporting and crisis management at higher levels such as the region or even the nation.

Virtualized and software based Unified Communication platform embedded in NexSIS 18-112 coupled with the creation of an ESInet constitutes the first operational implementation of the NG 112 standard in Europe. It will allow new communication paradigms such as the shift from the telephone to multimedia and data exchanges between the citizens, emergency centers and field operators. The increasing personalization and characterization of each emergency call should ultimately save many lives. The Digital Hub allows the improvement of communications between the different forces needed to answer to an emergency situation. The Digital Hub allows also to connect easily the growing number of mobile Apps 112 and to support VOST organization where citizens become active part of the emergency process.

AI, already present in the first version, opens a very large field of new applications and opportunities, which will be progressively incorporated in the NexSIS 18-112 platform.

The concepts and the technical architecture selected for this project seem to us to be able to provide a foundation for the development of cloud-based digital services for emergency forces.

Finally, we hope that the moto “NexSIS 18-112, the digital platform that saves lives” will become true when the project will enter in operational phase.

ACKNOWLEDGMENTS

This work was supported by the Civil Security Digital Agency funded by the French Ministry of Interior.

REFERENCES

Ali S, Kibria M.G., Jarwar M.A., Lee H.K., Chong I. A (2018) Model of Socially Connected Web Objects for IoT Application, *Wireless Communications and Mobile Computing, Volume 2018, Article ID 630950*

DGSCGC (2018) – Les statistiques des services d’incendie et de secours pour l’année 2017 (Édition 2018), *https://www.pompiers.fr/actualites/les-statistiques-des-services-dincendie-et-de-secours-pour-lannee-2017-edition-2018*

DISIC (2014) – Réseau Interministériel de l’État : ses trois grandes missions, *https://www.modernisation.gouv.fr/home/les-trois-grandes-missions-du-reseau-interministeriel-de-letat*

Dechter, R. (2003) – Constraint Processing, *Morgan Kaufman editor ISBN 1-55860-890-7*

Eidam, E. (2018) – Introducing VOST: A Way to Make Social Media work for Emergency Response, *Emergency Management, April 25, 2018*

European Commission (2017) – The interoperable EU-wide eCall,

https://ec.europa.eu/transport/themes/its/road/action_plan/ecall_en

Fielding, R. (2000) – Representational State Transfer (REST), *Architectural Styles and the Design of Network-based Software Architectures (Ph.D.), University of California, Irvine*

Jacobson V et Al. (2003) – RFC3550 RTP: A transport Protocol for Real-Time Applications, *IETF,* https://tools.ietf.org/html/rfc3550

Knorr, E. (2006) – Software as a service: The next big thing, *Computerworld 23 March, 2006*

Krebs, R. (2012) – Architectural Concerns in Multi-tenant SaaS Applications, *Proceeding of the 2nd International Conference on Cloud Computing and Services Science (CLOSER 2012) SciTePress*

Liberal, F. (2018) - EENA Associationn– NG112 and the new Emergency Service Networks landscape, *https://eena.org/wp-content/uploads/2018/11/Next-Generation-112-and-the-new-Emergency-Services-Networks-Landscape-compressed.pdf*

Lloyd, J. (1994) – Practical Advantages of Declarative Programming – Proceedings of the 1994 Conference on Declarative Programming, GULP-PRODE'94 Springer Verlag.

Lupinacci, J. (2015) – ESInets Are a Game Changer for Public Safety and First Step to Next-Gen 911, *Emergency Management, May 6, 2015*

Machado, G. et Al. (2016) – Advance Mobile Location (AML) Specifications and Requirements, https://eena.org/wp-content/uploads/2018/11/2016_03_02_AMLrequirement_FINAL.pdf, *EENA Org*

Parker, M. (2014) – What is Unified Communications? *Unified Communication Strategies, 11/12/2014*

Plitchenko, V. (2017) – Single-Page Apps : Advantages, Pitfalls, and Best-for Suggestions, *White Paper, Fri,21july 2017, Apriorit R&D services*

Rosenberg, D. (2008) – Web-oriented architecture and the rise of pragmatic SOA, *C/Net https://www.cnet.com/uk/news/web-oriented-architecture-and-the-rise-of-pragmatic-soa/*

Schooler E. et AL. (2002) – RFC 3261 SIP : Session Initiation Protocol, *IETF, https://tools.ietf.org/html/rfc3261*

Waters, J. (2013) – OASIS – Emergency Data Exchange Language (EDXL) Distribution Element Version 2.0, *http://docs.oasis-open.org/emergency/edxl-de/v2.0/edxl-de-v2.0.html*

Winterbottom, J. (2015) - EENA Association,– PEMEA (Pan-European Mobile Emergency Application, *https://eena.org/pemea-pan-european-mobile-emergency-application/*

VigiFlood: a serious game for understanding the challenges of risk communication

Carole Adam*
Univ. Grenoble-Alpes, LIG
mailto:Carole.Adam@imag.fr

Eric Andonoff
Univ. Toulouse Capitole, IRIT mailto:
Eric.Andonoff@ut-capitole.fr

v1.1.1
2018/09/10

ABSTRACT

Emergency managers receive communication training about the importance of being 'first, right and credible', which is not easy. For instance, in October 2018, the Aude department in the South-West of France was hit by intense rain. Flash floods were hard to forecast and only the 'orange' level of vigilance could be raised initially, but the population dismissed this very usual warning in that season. The 'red' level was then raised too late, leading to high criticism. The main problem here is the loss of trust induced by too many 'false alarms'. In this paper we propose a serious game called **VigiFlood** for raising awareness in the population about the difficulty of crisis communication and their own responsibility for reacting to the alerts. The implemented game still has limited functionality but already shows interesting results in helping the user to visualise and understand the trust dynamics.

Keywords

Flash floods, early warning, crisis communication, trust, agent-based modelling and simulation, serious game

INTRODUCTION

Nowadays, our societies are exposed to multiple risks: natural disasters, epidemics, terrorist attacks, industrial accidents, etc. During such disasters, the population has access to multiple sources of information (including images, videos or field information shared by other citizens), leading to possible confusion and information overload. As a result, they do not always listen to or trust official messages, and might not react appropriately. Emergency managers are therefore trained in risk communication and learn how to communicate in a timely and credible manner, while taking into account the psychology of their audience, in order to refute misinformation, and maintain trust and good relationships (Reynolds and Seeger 2014).

The question of **when** to raise an early warning about a predictable natural disaster is crucial: too late, and there might be many victims; but too early, and the clues might not be very reliable, leading to possible false alarms and subsequent loss of trust (Pearson 2012; Geleta 2013). For instance in October 2018, serious flash floods hit the Aude department in the South-West of France[1]. The day before, the level of vigilance was set to 'orange' (level 3 out of 4) for heavy rain and risk of flood, but the population did not react to that very usual warning for that season. When the vigilance was risen to 'red' (level 4 out of 4) early the next morning, it was too late and many towns and villages were already flooded. As a result, several people died and the authorities received severe critics.

There are several ways of addressing this problem: training the alert services to use the orange and red vigilance cautiously in order to avoid false alarms (Geleta 2013); providing them with decision-support systems to help raising timely early warnings (Friedemann et al. 2011; Behrens et al. 2008); or making the population **aware** of the difficulty of risk prediction and communication, and of their responsibility for still responding even after several false alarms. Here we focus on the **population**, and aim at providing them with a **serious game, VigiFlood** where

*corresponding author
[1]See for instance: https://www.bbc.com/news/world-europe-45861428

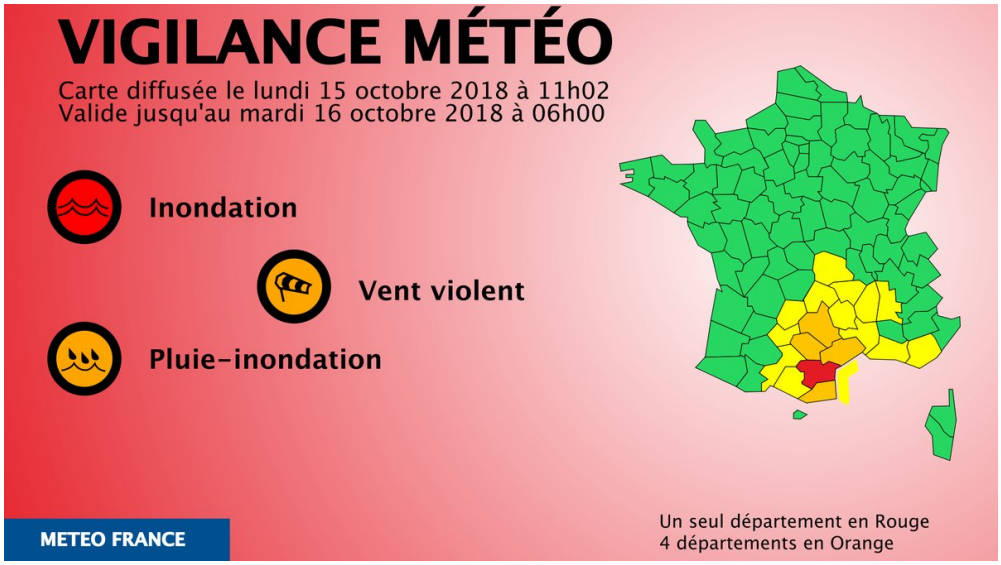


Figure 1. MeteoFrance vigilance map, 15 October, 11am (source: MeteoFrance)

they can play the role of an emergency communicator. They will have to set the vigilance level based on the (uncertain) weather forecast, and observe reactions in the simulated population. Our **hypothesis** is that this change of perspective will increase their awareness.

This paper is structured as follows: the first section provides some background about flash floods, crisis communication, trust dynamics, and existing simulators; the next section then describes our conceptual agent-based model; we follow up with exposing the implemented game and first experimental results, before concluding the paper.

BACKGROUND

Flash floods

Flash floods generally occur due to rapid rain on an already saturated soil (after a particularly wet period) or on a soil with a poor absorption capability (such as concrete, as is often the case in urbanised settings), or due to extensive rain because of a storm or hurricane. They can also occur from more occasional events such as a glacier melting after a volcanic eruption, an ice dam melting, or a man-made dam failing. In this paper we focus on rain-induced flash floods, whose prediction depends on the meteorological services.

The indicators used by forecast services include: forecast quantity of rain (radar or satellite or model based), soil absorption capacity, soil moisture or dryness level, topography, basin or catchment capacity, etc (CEPRI 2008). In France, the agency in charge of forecasting the expected amount of rain is Meteo France[2]. Weak rain is defined as 1 to 3 mm/h, moderate rain is between 4 and 7 mm/h, and heavy rain is over 8 mm/h. Another agency is in charge of monitoring the main waterways and broadcast their expected height and debit 3 to 6 hours ahead of time: Vigicrues[3]. However, only part of the waterways are monitored, and the European Flood Risk Prevision Center (CEPRI[4] notices that half of the 63 victims in the Languedoc-Roussillon region (south of France) alone between 1996 and 2006 died on catchment basins that were not monitored by flood vigilance services.

The meteorological services in charge of the area then analyses these clues (rain forecast, waterway height and debit, etc) to define and announce a level of vigilance on a 4-colour scale, from green (no problem), yellow, orange, to red (higher risk). This level of vigilance is publicly available online[5] (example map on Figure 1). Each region has its particularities and can be more or less used to receiving heavy rain in a short amount of time, so that the vigilance thresholds are not the same everywhere. The Aude department in France (see map on Figure 2) depends on the CNP center in Toulouse; its critical rain threshold for the orange vigilance is 50-100 mm in 24 hours, with a regional record of 551 mm in 24 hours. On Sunday 14 October 2018 the meteorological station of Carcassonne received 139.8 mm of rain. However the vigilance level was first only set to orange, until Monday 15 October morning at 6am when it was finally raised to red. As a result, MeteoFrance vigilance system was harshly criticised

[2] http://www.meteofrance.com/previsions-meteo-france/previsions-pluie
[3] www.vigicrues.gouv.fr
[4] https://www.cepri.net/
[5] For instance at: http://vigilance-public.meteo.fr/ or http://vigilance.meteofrance.com/

Figure 2. Map of the flooded area, with victim counts, and evacuated towns. Source: Préfecture de l'Aude

in the media (Libération-AFP 2018). The representative of the Ministry of the Interior, Frédéric de Lanouvelle, interviewed on LCI-TV, evoked a *"weakness in the orange vigilance level which is used very often and when there is a real problem, people do not take it into account anymore"* (our translation). He adds that based on residents' statements, the red vigilance level was indeed raised too late, but explains it is due to the difficulty in forecasting such a powerful episode.

Flood simulations

Axelrod (1997) defines 7 purposes of simulations, including prediction (simulate a system very realistically to predict its future behaviour, *e.g.* meteorology), training (provide a believable interactive environment to rehearse actions, *e.g.* flight simulator), or education (let the user learn by trying in a virtual world). Predictive simulations require a high degree of realism to lay valid predictions, while training and education simulations can be simpler and less realistic (they "need not be rich enough to suggest a complete real or imaginary world"). Besides, Axelrod also claims that "the simpler the model, the easier it may be to discover and understand the subtle effects of its hypothesized mechanisms"; educational simulations are therefore often quite simple.

Simulations have often been used in crisis management for various purposes. For instance (Yang et al. 2018) provide a very realistic model based on field data, to **predict** the impact of early warnings on population behaviour in terms of reducing material losses from floods. Others focus on realistically modelling the physical flood phenomenon in order to **support decisions** regarding early warnings for tsunamis (Friedemann et al. 2011), based on data from multiple sensors (Behrens et al. 2008).

Other simulations are aimed at **education**, often in the form of a serious game. Anycare is a table-top role-playing game to involve stakeholders (Terti et al. 2019). LittoSIM (Becu et al. 2017) is very realistic and aimed at emergency managers; SPRITE (Taillandier and Adam 2018) teaches risk management to engineering students; however both games focus on longer-term management and protection against coastal submersion (*e.g.* building dykes) rather than communication.

Other simulations focus on communication, but not necessarily during floods. (Arru et al. 2019) study if the population should be alerted or not of an ongoing crisis (*e.g.* terrorist attack), depending on the anticipation of their potential reaction (*e.g.* crowd panic), which is based on a psychological model. Since events considered are ongoing, they do not deal with false alarms and their potential impact on long-term trust. (Adam and Dugdale 2018) study the propagation of awareness in the Australian population after a bushfires warning, depending on its channel and (familiar vs unfamiliar) source. Since they consider a single event, they do not deal with long-term dynamics of trust over multiple (right and wrong) alerts. (Adam, Bailly, et al. 2019) also proposed a serious game for trying various communication strategies to alert the population (focused vs wide targeting, information vs recommendations) before and during fires, but they do not deal with the timing of alerts nor the impact of false alerts. Indeed, they report no habituation phenomenon to fire alerts, which could be due to the easier predictability of fires compared to flash floods, or to normative and cultural differences.

Crisis communication

Reynolds (2010) identifies 6 principles of efficient crisis emergency and risk communication (CERC):

- **Be First**: in times of crisis, people need information fast, and will often stick with the first source they get information from.
- **Be Right**: information should be accurate and transparent, explaining what is known or not, and what is being done to get more information.
- **Be Credible**: communicators should be honest and trustful, and avoid to promise what they cannot deliver, at the risk of losing the public's trust.
- **Express Empathy**: communicators should acknowledge the population feelings and challenges to build trust and a good relationship.
- **Promote Action**: messages should not only be informative but also action-oriented, to empower the population, give them a feeling of control, and release their anxiety.
- **Show Respect**: communicators should account for the vulnerability of people during crises, their messages should be respectful and promote cooperation and rapport.

(Infanti et al. 2013) review the literature to explain the "complex and unpredictable ways that individuals perceive risk", and find that risk communication is influenced by socio-cultural, environmental and linguistic factors. Covello *et al.* (2001; 2003) identify 4 factors of risk communication:

- **Risk perception** is subjective, influenced by socio-cultural and cognitive factors (*e.g.* the individual feeling of agency or control).
- **Mental noise** created by stress and threat reduces the ability to process information: technical and scientific concepts must be "translated [...] into understandable messages", which should be visual and repeated.
- **Negative dominance**: upset people focus more on negative (losses) than positive (gains) information, so communication must counter-balance negative messages with many more positive, action-oriented messages, and focus on progress rather than failures.
- **Trust determination**: upset people tend to not trust authority, so trust must be created well ahead of any crisis, through proactive community communication.

Further, (Hurnen and McClure 1997) discuss the importance of the locus of control of individuals: if **external** (*i.e.* they believe they have no control) they will feel helpless, and be less likely to take preventative action or react to warnings than if **internal** (*i.e.* they believe they can do something). This is in line with the CERC principle to 'promote action' and give people something to do so that they feel (more) in control. Similarly, (Khan et al. 2012) discusses the lack of response of the population when the perceived risk is either too high (fatalism) or too low ("blasé effect"): in both cases, people feel powerless. He concludes by recommending to pay careful attention to the level of risk that is communicated to the population in the warnings to avoid undesirable reactions or inertia.

The American Center for Disease Control and Prevention issued a report about Crisis and Emergency Risk Communication (Reynolds and Seeger 2014) focusing on specific psychological factors of information processing during a crisis, and how messages should be adapted subsequently:

- People **simplify** messages, might not hear, not remember, or misinterpret them. Logical reasoning is impaired and decisions might rely more on habits, routines or imitation. Messages should therefore be simple.
- People **hold** on to their current beliefs, and prefer trusted and familiar sources of information even if inaccurate and non-expert, to reputable experts who might disagree with each other. Messages should therefore come from credible sources.
- People try to **confirm** information before acting, via complementary information and additional opinions. Messages should therefore be consistent between the different channels.
- People believe the **first** message, and compare any further message with it; lack of information creates anxiety, leading to speculation and rumors. Accurate messages should therefore be released as early as possible.

These findings are in line with research showing the importance of cognitive biases in disasters (Murata et al. 2015; Arnaud et al. 2017).

Trust and risk

According to Slovic (2016), risk management has become much more "contentious", with risk managers blaming the public for being irrational, and the public blaming the stakeholders for their poor management. In his view risk communication, aiming at aligning population and experts' perceptions with experts, has failed due to the lack of trust: "if trust is lacking, no form or process of communication will be satisfactory" (p. 410).

Slovic also explains that trust is "fragile", builds up slowly but can be destroyed instantly and is then hard or impossible to regain (p. 319). He provides several reasons for this asymmetry:

- Negative events are more visible than positive ones (one missed alarm stands out in many days of correct predictions);
- Negative events have more weight because they have lower probability and higher consequences (a flood is rarer than a "normal day" and can do serious damage);
- The media also tends to give more coverage to bad news than good news;
- Sources of bad news are seen as more credible, less likely to lie, than sources of good news;
- Distrust strengthens itself, by limiting further interactions and biasing future interpretations towards the reinforcement of existing (distrustful) beliefs.

Conclusion

Existing simulators are most often aimed at training or supporting decisions of emergency managers. We adopt a different approach where we propose a serious game aimed at changing the population's perspective by letting them play the role of an emergency manager confronted with difficult decisions.

This approach is in line with the risk communication principles advocating transparency and empowerment of the population (Reynolds 2010), and is currently lacking research. Our claim is that such a game will improve the population's awareness of the difficulty to predict and announce natural disasters, and their responsibility to react despite a certain rate of (unavoidable) false alarms.

Our serious game is based on a conceptual agent-based model of human behaviour in flash floods. The validity of the underlying behaviour model is ensured by its grounding in psychological and sociological theories of trust and risk communication described above. The physical model of flood on the other hand need not be extremely realistic to reach our educational goal, in line with (Axelrod 1997). This conceptual model is described in the next section.

CONCEPTUAL AGENT-BASED MODEL

The hazard: flash flood

Among the many available clues used by hydrologists and meteorologists to forecast floods, we selected only clues understandable by non-specialists players. As discussed above, this simplified model is more likely to be understood, and sufficient for educational purposes (Axelrod 1997). Figure 3 provides a representation of our environment model in the Unified Modelling Language (UML). Each area has various attributes: its name, geographical coordinates, population, rain forecast, vigilance level; rivers in this area (name, dangerousness, overflow height, water height and vigilance level); buildings (name, type, are they safe, are they official shelters, distance to water, altitude); history of hazards and their severity.

The weather forecast services (MeteoFrance) is represented as an agent having a precision attribute (0-100%); it predicts the expected amount of rain (in mm). The emergency manager (human-piloted agent) relies on this rain forecast to sets the vigilance colour that is communicated to the population.

Population

The population is composed of a number of heterogeneous civilian agents, whose attributes are listed in Table 1. Civilians receive vigilance alerts from the emergency manager, and observe real rain. The core of their behaviour is their subjective evaluation of risk (*i.e.* expected rain) based on their (dynamic) **trust** in the vigilance alerts, their **memory depth** (how many past events they can remember), and their **update strategy**. This strategy reflects their personality: optimistic (consider the minimum amount of rain observed during past events where the same vigilance colour was raised; if a false alarm was raised in the past this can lead to expect no or very little rain); pessimistic

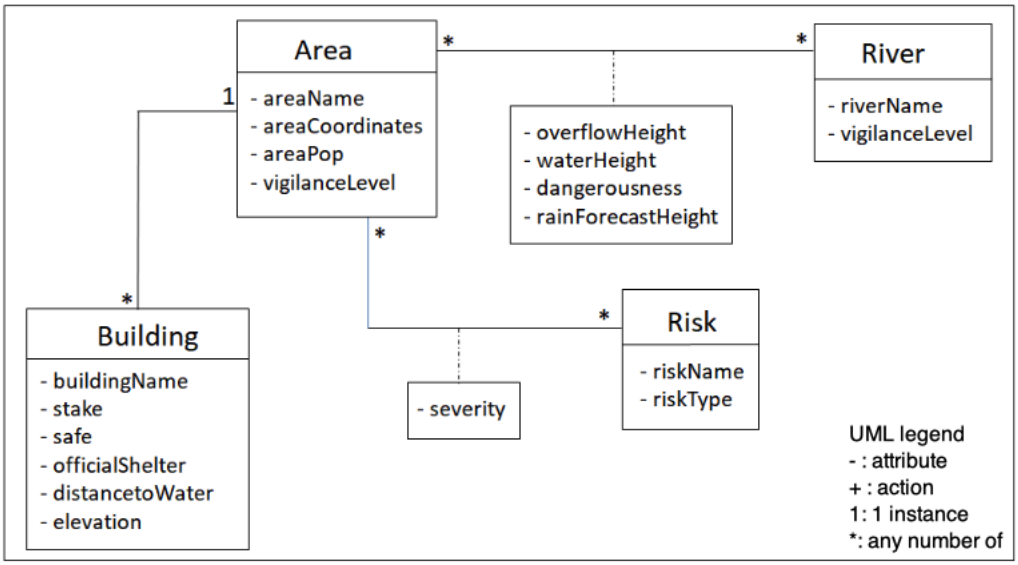


Figure 3. UML conceptual representation of the environment in which flash floods occur. Boxes are the classes, linked by relations with numbers indicating the number of instances. For instance the link between 'building' and 'area' states that a building can be in 1 area only; an area can contain any number of buildings.

(consider the maximum amount of rain; this is very forgiving to false alarms); rational (consider an average of observed rain on past occurrences); or short-memory (consider only the last occurrence). This process is in line with psychological theories saying that humans evaluate risk based on previous experience and emotions (Reynolds and Seeger 2014).

Trust then mediates the relative importance of the official vs personal forecast: if trust is 100%, the civilian will expect exactly the amount of rain corresponding to the vigilance colour; if it is 0% they will expect the subjective value resulting from their past experience, which can be quite low after many false alerts.

Finally the civilians' decision to evacuate is based on the comparison of this subjective value with a personal risk aversion threshold (initialised randomly), which can lead to delays in evacuation if expected rain is under-estimated. Civilians can also evacuate after directly observing high amounts of rain (exceeding their aversion threshold), but this often happens too late.

Attribute name	Range of values	Initialisation
Initial trust	0-100%	Parameter
Subjective risk	0-?? mm	0 (no risk)
Update strategy	min, max, avg, last	Parameter
Memory depth	5-10 events	Random uniform
Evacuated	True, False	False
Risk aversion threshold	50-100 mm	Random uniform

Table 1. Attributes of civilian agents

IMPLEMENTATION

Goal of the game

The VigiFlood serious game is **targeted at the population**, with the **goal** of raising their awareness about the difficulty of choosing the right level of alert under uncertainty and high stakes. This is done by changing the player's perspective, getting normal citizens to play the role of an emergency manager having to set the level of flood vigilance based on uncertain rain forecast before facing the population reaction. Our **hypothesis** is that this change of perspective will improve awareness of risk communication challenges.

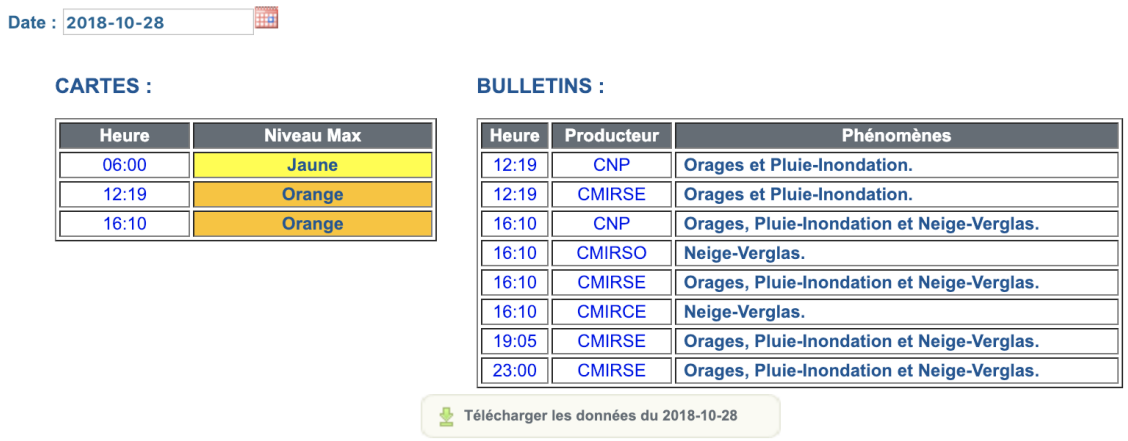


Figure 4. Example of Vigilance Public Meteo output for 28 October 2018

Real data

Getting the data

We implemented 2 Python scripts to extract two types of meteorological data useful to our serious game (rain and vigilance level) from websites where archives are publicly available.

- Rain data: Infoclimat[6] provides archives of daily, monthly and yearly meteorological data since 1973: temperatures, wind, rain, etc. The earlier years can be incomplete. We have implemented a Python parser `getraindata` (300 lines) to extract the following data: normal monthly rain (seasonal norms computed by Infoclimat between 1981-2010), number of days of rain (at least 1 mm) per month, and actual daily readings of rain amounts. We used this parser for Carcassonne-Salvaza (station number 07635) for the years 2010-2018.
- Vigilance data: Vigilance Public Meteo[7] provides a PHP interface (see Figure 4) letting users search for a specific date to get information about vigilance alerts in the entire country that day: time, level (green, yellow, orange, red), emitting agency (each covering a different region; Aude department depends on the CNP agency in Toulouse), and phenomenon concerned (floods, high winds, waves and coastal submersion, snow and black ice, etc). We implemented another parser, `getvigidata` (300 lines) that can query this website for a series of dates (we used it between 2010 and 2018), download the alert bulletins (XML files), select only relevant ones (emitted by CNP, concerning floods). We searched each bulletin for the vigilance colour associated with rain and floods only. When there was no bulletin for a date, we set the colour to green; when there were several, we kept the highest colour.

The output of both scripts is a dictionary dumped to a binary file (with the `pickle` module) that can be loaded from any other Python script to recover the entire dataset.

Difficulties and limitations

Our main difficulty was handling missing and inconsistently formatted data. First, some daily rain data was missing, in particular for the earlier years, which is why we only extracted data after 2010, but some days are still missing. Also the format of the vigilance bulletins was not always consistent, making it hard to extract the exact colour of the flood alert. Besides, on yellow vigilance days, no bulletin was issued. This means that for these days, in the absence of information, our parser will extract a green vigilance instead of yellow. In fact out of 3294 vigilance values, we have 3009 green days, 274 orange days, 11 red days, and no yellow days. To improve this, we need to find another source of vigilance information that also provides yellow alerts; however this is not too much of a problem in this paper since we are mainly interested in the habituation to orange alerts.

Finally, the vigilance level that we extract concerns the entire area covered by the CNP agency, while our daily rain values concerns the Carcassonne-Salvaza meteorological station. This means that the vigilance level is not always

[6] https://www.infoclimat.fr. For instance, archives for Carcassonne-Salvaza for the entire month of January 2010: https://www.infoclimat.fr/climatologie-mensuelle/07635/janvier/2010/carcassonne-salvaza.html and for a specific day 2 January 2010: https://www.infoclimat.fr/observations-meteo/archives/2/janvier/2010/carcassonne-salvaza/07635.html

[7] http://vigilance-public.meteo.fr/

consistent with the actual rain amount, when the floods are located in a different part of the South-West region. In our model, this might be interpreted by the residents as a false alarm because an orange vigilance is raised but the observed amount of rain does not match; in reality, humans would understand which area is concerned with the vigilance; to improve this we would need to mine the text of the bulletin for the locations concerned.

Genericity

Data could be recovered from the same sources for other regions with minimal adjustment of the scripts. Data from any source and in any format can also be fed to the game provided it is saved in the expected input dictionary format, making the game generic and easily adaptable to different areas. We are indeed currently discussing with Grenoble township to get local flood data and provide them with an adaptation of VigiFlood. What might change however is the human reaction to floods, that are much less frequent in Grenoble than in Carcassonne.

More realistic hydrological data

Our current model only relies on the forecast height of rain to set the level of vigilance. To improve scenarios realism without undue complexification of the model, we intend in future versions to add a few more relevant clues, namely soil saturation and river capacity. We will use real hydrological data from various national waterways monitoring agencies[8]. This will require implementing new data extraction scripts and working with hydrologists to design a realistic model of the flash flood process and its prediction.

Implemented game

Technical details

Our current program is a 1800-line Python script. It uses the `pickle` module to load the data created by our previous scripts (`getraindata` and `getvigidata`) from local dump files. This is done only once at the start of the program, and the object created can then be used for the duration of the game. The game has a textual (screenshot on Figure 5) or graphical (screenshot on Figure 6) interface, in either French or English. A batch simulation (no output) over 1 year of simulated time, with 10 repeats and a population of 100 agents, runs in about 120 seconds; with a population of 10000 agents one repeat runs for almost 20 minutes.

Game parameters

Before playing, the user can set a number of parameters:

- **Population size**: number of residents in the population.
- **Starting date**: between 1st of January 2010 and December 2018, which is the range covered by our data.
- **Duration of the game**: in days (at the latest the game stops on December 31st, 2018).
- **Trust initialisation**: either heterogeneous with random initial trust for each resident; or homogeneous with a set initial trust value for all residents (between 0 and 100%).
- **Risk update strategy**: residents can update their subjective risk (expected amount of rain) based on the minimum, maximum, average, or last amount of rain observed on the past occurrences (that they can remember) of the same vigilance level. This strategy is chosen as a parameter and is the same for the entire population.
- **Precision of rain forecast**: the weather forecaster agent computes forecasted rain based on monthly norm of rain, real observed rain for the next day, and precision parameter (0-100%). With higher precision, the forecast is closer to real rain, while lower precision predicts values closer to the norm, potentially missing exceptional events.
- **Interface parameters**: the user can choose between textual or graphical interface, can toggle text feedback on/off, and can choose between French and English language.

[8] In particular `http://www.hydro.eaufrance.fr/` and `https://www.vigicrues.gouv.fr/`

Game loop

The game loop proceeds as follows:

1. The date of the day is displayed, as well as the observed amount of rain that day (in mm).
2. The residents react to the observation of the rain: they compare it with the current vigilance level (set the day before) to update trust, and they might evacuate if needed.
3. The player is provided with feedback about the population: average trust and its explanation (in terms of how much rain they expected based on the vigilance colour); and percentage of evacuated residents.
4. The weather forecast service announces a forecast amount of rain for the next day.
5. The player is asked to set a vigilance colour based on this forecast.
6. The population reacts to this vigilance level: compute subjective expected rain based on previous similar alerts, and might evacuate if this is above their risk aversion threshold;
7. The player receives feedback about the percentage of the population aware of the risk (if any); their average expected rain (in mm); their average trust (in %); and the percentage that evacuated as a result of the alert.
8. Rain and vigilance for the day are stored in game history, and the time moves forward to the next day.

Getting feedback

At the end of the game, final feedback is displayed in the form of statistics about the population and communication:

- **Population statistics**: average percentage that stay unaware of risk; average expected amount of rain for each vigilance colour; average trust and its evolution before/after the game; and average evacuation percentage.
- **Communication statistics**: total days played; for each colour: number of alarms raised, number of false alarms (raised but observed rain lower than expected), number of alarms missed (not raised and observed rain higher than expected).

Game modes

We have implemented 4 possible game modes:

- **Visualisation**: this mode lets the user explore the available data. The user inputs any date since 2010 and obtains the amount of rain in Carcassonne on that day as well as the vigilance level.
- **Play**: the user chooses the desired parameters, and plays the role of the emergency communicator in charge of setting the vigilance level. The game proceeds along the loop described above for the selected number of days, and final feedback is provided to let the player debrief his actions.
- **Automatic**: in this mode the human player is replaced with an AI that automatically selects the vigilance level based on the rain forecast (above 10mm: yellow, above 20mm: orange, above 50mm: red). The same final feedback is displayed at the end. This allows to compare human players' strategies with a predefined static strategy.
- **Batch**: in this mode all displays are disabled and the game is repeated a number of times with the same initialisation to smooth out the randomness. The output is an average of the trust evolution over all games played with these same parameters. This allows to draw statistics and compare the impact of each parameter.

```
************************************
************************************
***                              ***
***                              ***
***      WELCOME TO VIGIFLOOD    ***
***                              ***
***                              ***
************************************
************************************

Bonjour, hello !
[Language (en/fr)? : en
Game in english
[Mode: (v)isu, (a)uto, (p)lay, (q)uit? : p
Play mode
[What's your name? : A. Nonymous
[Population size ? : 100
[Day ? : 1
[Month ? : 10
[Year ? : 2018
[How many days do you want to play? : 50
[Trust initialisation: random (-1), null (0), homogeneous (1-100%)? : 70
[Compute risk based on (min), (max), (last), (avg) of past events? : min
[Precision (0-100%) of forecast predictions? : 50

Initial population, average trust =  70.0 %


*************
Today is:  1 October 2018
Observed rain:  0.0 mm

Population observes rain 0.0
Vigilance:  Verte meant rain in [ 0 mm ; 10 mm]
Average trust:  70.0 %  ( 70.0 % :  +0 )
Evacuation percentage:  0.0 %


Weather forecasters announce:  0.96 mm of rain tomorrow
[Vigilance? : Green
Vigilance  Green

Population reacts to vigilance
Percentage unaware:  0.0 %
Average expected rain:  3.5 mm
Average trust:  70.0 %  ( 70.0 % :  +0 )
Evacuation percentage:  0.0 %
```

Figure 5. Screenshot of the textual game interface in "play" mode

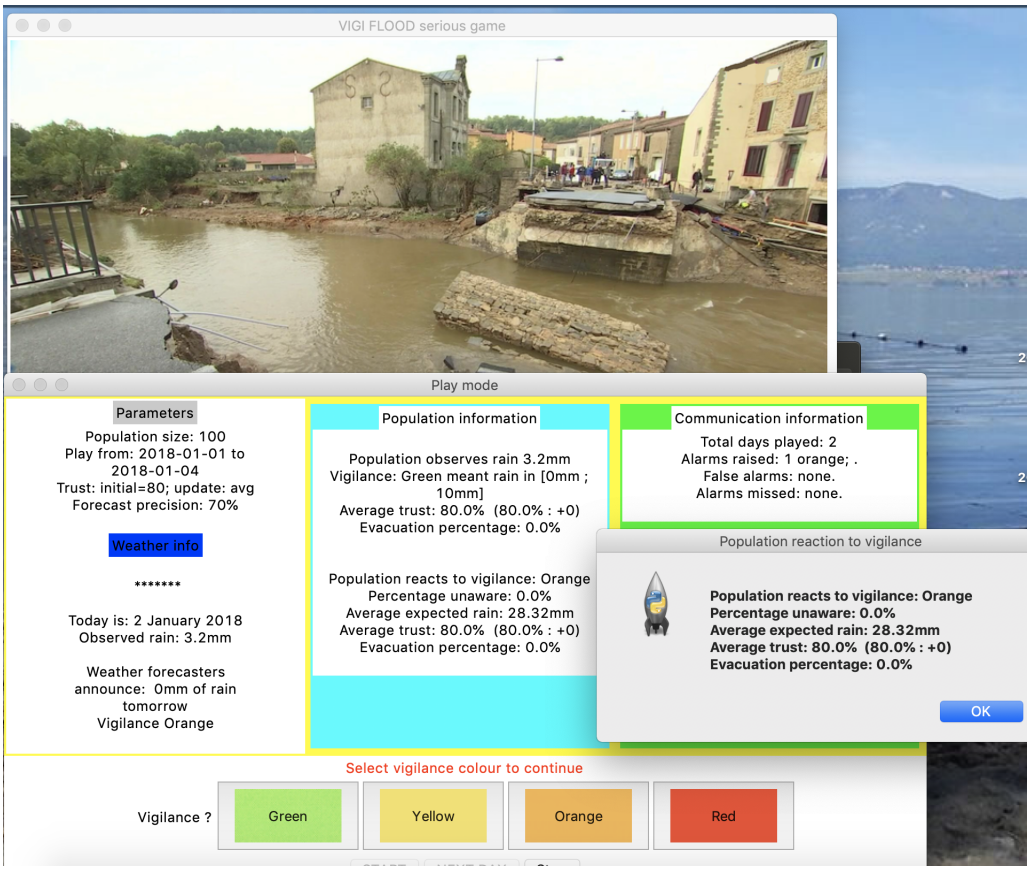


Figure 6. Graphical interface of VigiFlood during a game

PRELIMINARY RESULTS

Scenario 1: forecast precision

We have run a first scenario in order to explore the positive and negative evolution of population trust in function of the precision of the weather forecast. We have run the simulation for 3 months, starting October 1st 2018, and therefore including the events of October 14-15, on a population of 100 agents. The population was defined with random heterogeneous initial trust (around an average of about 50%) and their algorithm for computing expected rain is based on the average of past rain. With these settings, we only varied the precision of rain forecast and observed the evolution of trust over these 90 days.

- Perfect forecast (100% precision of the rain forecast): trust increased slightly from an average of 52.81% to an average of 58.71%.
- Realistic forecast (80% precision): average trust remained stable around 50% (from 49.76% to 49.65% exactly).
- Same but with 50% forecast precision: the average trust dropped from 54.23% to only 22.57%.

First, we observe that trust decreases faster than it increases: lost trust is hard to restore, so it is best to maintain trust. Second, this shows the importance of reliable forecast to set an accurate vigilance level, yet flash floods are hard to predict because they depend on many other factors than just rain. It is therefore very important that the population is made aware of these difficulties and the fact that false alarms are unavoidable. This is part of being transparent in order to maintain trust, as recommended by (Reynolds 2010).

Scenario 2: population reasoning

The scenario above was based on an averaging of past events, and an "objective" update of trust where observed rain was compared with the objective meaning of the vigilance colour. This means that if the vigilance level was set to orange, the observed rain was compared to the official 20-30mm range supposed to be meant by that alert. But the population actually relies on a subjective expected rain based on their previous experience of past orange vigilance days; this is how they get habituated to this orange vigilance meaning "not much", when it is raised and it does not rain much. We have therefore run another set of games with a subjective update of trust based on comparing observed rain with the individual's subjective expectation, computed using our various algorithms. We have set the forecast precision to 100% and run 90 days during year 2010 to limit the number of false alarms in history. Results are very sensitive to the period played and which events occurred:

- The averaging of past rain on same-vigilance days: this strategy considers the more different past alerts, and leads to the worst loss of trust when there are many false alarms. However, correct alarms in the past history will improve the subjective prediction and hence the final trust of the population.
- The "last-event only" strategy means that after a false alarm, the next alarm will be inefficient, people will expect it to be just as false. But then only one correct alarm is enough to reset expectations.
- The "maximal last event" strategy makes residents pessimistic, they will expect as much rain as the worst event on record; the player might lose some amount of trust for announcing too much rain, but people will rather react too much than not enough.
- The "minimal last event" strategy on the other hand makes residents more optimistic: they will only expect as much rain as the lowest rain that occurred in the past when vigilance was set to that same level. This means that they are very likely to not react to an orange vigilance, for instance, as long as they have not forgotten that one day when it was raised and it did not rain.

In reality, we expect humans to use combinations of these strategies, possibly dynamic depending on the context and their personality. Changes are therefore needed in our game to improve the residents' reasoning, and also to make it heterogeneous. However, validating this reasoning strategy would require to find supporting data about how people actually reason about subjective risk, which might be difficult.

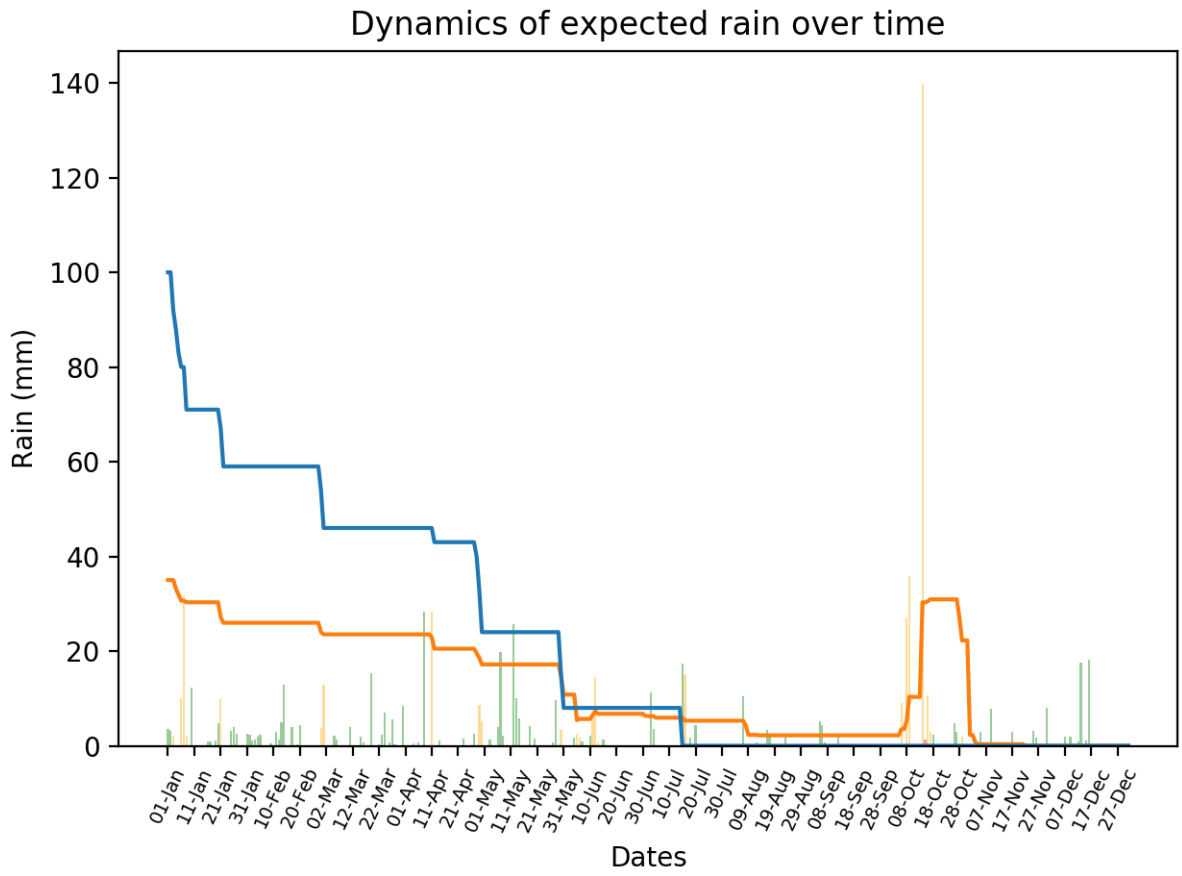


Figure 7. Dynamics of trust (blue line), expected rain associated with orange vigilance (orange line), observed rain (bars height), and vigilance (bars colour), over year 2018.

Visualising the dynamics of trust

Figure 7 illustrates the dynamics of trust in the population over the real events of year 2018. We initialised the population with full trust (100%), a 'realistic' update strategy (averaging past rain on orange vigilance days in memory) and a memory depth of 7. One can see that at the start of the year, trust is 100% (blue curve) and the expected amount of rain on orange vigilance days (orange curve) is around 35 (the middle of the official 20-50 mm range).

The bar chart shows the actual amount of rain observed each day, and the colour of each bar shows the associated vigilance colour as announced by the authorities. As the year progresses, various 'false alarms' are raised where orange vigilance is announced but it does not rain much: as a result, trust goes down, and the average expected rain on orange days also decreases, making the residents more likely to be surprised in case intense rain really occurs. This is the case in October, when the orange vigilance is set on the 14. A positive effect of this surprise is that the expected amount of rain on orange vigilance days goes up again (counting that exceptional event in the average), but a negative effect is that trust drops near 0.

We believe such visualisations can be very helpful for people (residents or emergency managers alike) to understand the dynamics of trust in crisis communication. This makes our model already useful as a visualisation, before it is even interactive and playable.

Discussion

The game exposed here is just a proof-of-concept with limited playability, preventing immediate evaluation. The main obstacle to playability is the repetitiveness of the game that makes it quickly boring. So far the player is asked everyday to set a vigilance colour, while most days almost no rain is forecasted and the vigilance will be green more often than not. This will be improved by creating pedagogical scenarios that do not rely on actual past data, but that trigger more frequent interesting events in order to engage the player. Other ideas for improvement include using an

interactive map built from OpenStreetMap data, similar to other serious games used in emergency management (for instance SPRITE (Taillandier and Adam 2018)); and displaying feedback about emotions of the population.

We would also like to explore other scenarios, in particular assessing the impact of the vigilance thresholds (10mm for yellow, 20mm for orange, 50mm for red) on the average trust of the population and their subjective expected rain, depending on the forecast precision. This will require implementing various (automated) strategies with dynamic vigilance thresholds, and making the choice a parameter of the automated player.

Prospective evaluation of the game

As discussed above, the underlying behaviour model is grounded on psychological theories and is realistic enough for an educational purpose. What requires evaluation however is the **impact of the game**. In order to verify our claim that playing this game can **improve awareness**, we have planned the following evaluation process.

Once the playability of the game has been improved, the first evaluation will be with other researchers and students in our university or at workshops and conferences, in order to refine gameplay and interface; this can happen at medium-term. The second evaluation will require to first implement a logging functionality to store the history of players' actions, and to analyse logs to draw interesting statistics. We will then be able to analyse players' strategies to face the different pedagogical scenarios that we define, and observe how they adapt over time to measure the evolution of their awareness.

Finally, a more complex evaluation will be in the form of a survey of people in the affected area (Aude) in order to assess their trust in orange vigilance and will to act on it, before and after playing the game. This survey will also gather their qualitative feedback about the game. This can only happen at longer-term, after finalising the game and carefully designing the experimental protocol and questionnaire.

CONCLUSION

In this paper we have presented the **VigiFlood** serious game, a disaster alert game based on a real case study, the flash floods in the Aude department in October 2018. Although preliminary, the game is based on real pluviometric and vigilance data from local weather forecast agencies, and already provides interesting insight and novelty compared to previous work. In particular we have shown that it allows the player to visualise the dynamics of trust over time, and the impact of events such as repeated false alarms.

This game is however still a preliminary proof-of-concept and many things remain to improve. The implementation of more roles (journalists, etc) is already ongoing and should be finished at short-term, allowing us to explore more complex pedagogical scenarios. In the longer term we then want to improve playability, evaluate the game and its impact on awareness, and adapt it to other contexts.

REFERENCES

Adam, C., Bailly, C., and Dugdale, J. (2019). "Communication During Bushfires, Towards a Serious Game for a Serious Matter". In: *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)* 10.2. Ed. by Banuls Silvera.

Adam, C. and Dugdale, J. (2018). "Agent-based analysis of the spread of awareness in the population in the prodromal phase of bushfires". In: *Proceedings of the 51st Hawaii International Conference on System Sciences*.

Arnaud, M., Adam, C., and Dugdale, J. (2017). "The role of cognitive biases in reactions to bushfires". In: *ISCRAM, Albi*.

Arru, M., Negre, E., and Rosenthal-Sabroux, C. (2019). "To alert or not to alert? That is the question". In: *HICSS-52*, pp. 649–658.

Axelrod, R. (1997). "Advancing the art of simulation in the social sciences". In: *Simulating social phenomena*. Springer, pp. 21–40.

Becu, N., Amalric, M., Anselme, B., Beck, E., Bertin, X., Delay, E., Long, N., Marilleau, N., Pignon-Mussaud, C., and Rousseaux, F. (2017). "Participatory simulation to foster social learning on coastal flooding prevention". In: *Environmental modelling & software* 98, pp. 1–11.

Behrens, J., Klaschka, F., Mentrup, L., Raape, U., Strobl, C., Tessmann, S., and Riedlinger, T. (2008). "Handling uncertainty in tsunami early warning: interaction between decision support and multi-sensor simulation system". In: *International Conference on Tsunami Warning (ICTW)*.

CEPRI (2008). *Prévision et anticipation des crues et des inondations*. Tech. rep. Paris, France: Centre Européen de Prévention du Risque Inondation.

Covello, V. T. (2003). "Best practices in public health risk and crisis communication". In: *Journal of Health Communication* 8.1, pp. 5–8.

Covello, V. and Sandman, P. M. (2001). "Risk communication: evolution and revolution". In: *Solutions to an Environment in Peril*, pp. 164–178.

Friedemann, M., Raape, U., Tessmann, S., Schoeckel, T., and Strobl, C. (2011). "Explicit modeling and visualization of imperfect information in the context of decision support for tsunami early warning in Indonesia". In: *Symposium on Human Interface*. Springer, pp. 201–210.

Geleta, B. (2013). *Community early warning systems: guiding principles*. Tech. rep. Red Cross.

Hurnen, F. and McClure, J. (1997). "The effect of increased earthquake knowledge on perceived preventability of earthquake damage". In: *Australas. J. Disaster Trauma Stud.* 3.

Infanti, J., Sixsmith, J., Barry, M., Nunez-Cordoba, J., Oroviogoicoechea-Ortega, C., and Guillen-Grima, F. (2013). *A literature review on effective risk communication for the prevention and control of communicable diseases in Europe.* Tech. rep. Stockholm: European Centre for Disease Prevention and Control.

Khan, S., Crozier, M., and Kennedy, D. (2012). "Influences of place characteristics on hazards, perception and response: a case study of the hazardscape of the Wellington Region, New Zealand". In: *Natural Hazards* 62.2, pp. 501–529.

Libération-AFP (2018). "Aude, 12 morts dans les inondations : la vigilance rouge déclenchée trop tard ?" In: *Libération (15 October 2018)*.

Murata, A., Nakamura, T., and Karwowski, W. (2015). "Influence of cognitive biases in distorting decision making and leading to critical unfavorable incidents". In: *Safety* 1.1, pp. 44–58.

Pearson, L. (2012). *Early warning of disasters: Facts and figures*. Tech. rep. Sci Dev Net.

Reynolds, B. (2010). "Principles to enable leaders to navigate the harsh realities of crisis and risk communication". In: *Journal of Business Continuity & Emergency Planning* 4.3, pp. 262–273.

Reynolds, B. and Seeger, M. (2014). *Psychology of a crisis*. Tech. rep. US department of health, human services. Center for disease control, and prevention.

Slovic, P. (2016). "Perceived risk, trust and democracy". In: *The perception of risk*. Routledge. Chap. 19, pp. 316–326.

Taillandier, F. and Adam, C. (2018). "A serious game for teaching natural risk management". In: *Simulation & Gaming* 49.4, pp. 441–470.

Terti, G., Ruin, I., Kalas, M., Láng, I., Cangròs i Alonso, A., Sabbatini, T., and Lorini, V. (2019). "ANYCaRE: a role-playing game to investigate crisis decision-making and communication challenges in weather-related hazards". In: *Natural Hazards and Earth System Sciences* 19.3, pp. 507–533.

Yang, L. E., Scheffran, J., Süsser, D., Dawson, R., and Chen, Y. D. (2018). "Assessment of flood losses with household responses: Agent-based simulation in an urban catchment area". In: *Environmental Modeling & Assessment* 23.4, pp. 369–388.

Multi-agent geospatial simulation of human interactions and behaviour in bushfires

Lyuba Mancheva
Univ. Grenoble Alpes, LIG,
F-38000 Grenoble, France
lyuba.mancheva@univ-grenoble-alpes.fr

Carole Adam
Univ. Grenoble Alpes, LIG,
F-38000 Grenoble, France
carole.adam@univ-grenoble-alpes.fr

Julie Dugdale
Univ. Grenoble Alpes, LIG,
F-38000 Grenoble, France
julie.dugdale@univ-grenoble-alpes.fr

ABSTRACT

Understanding human behaviour and interactions in risk situations may help to improve crisis management strategies in order to avoid the worst scenarios. In this paper we present a geospatial agent-based model and simulation of human behaviour in bushfires. We have modelled the social interactions between different actors involved in bushfires such as firefighter, police, emergency centre managers and civilians. We use the Belief, Desire and Intention (BDI) architecture to model realistic human behaviour, and the FIPA-ACL standard to model the communications. We use geospatial data to represent the environment in a realistic way. We show how the model has been implemented and how we have unified the communications model and the BDI architecture. Finally, we compare the processing time of two implementations of our model representing a 2D simple and a 3D GIS environment.

Keywords

Multi-agent systems, cognitive agents, GIS, communication, bushfires

INTRODUCTION

Between 1998 and 2017 climate-related and geophysical disasters killed 1.3 million people and left a further 4.4 billion injured, homeless, displaced or in need of emergency assistance (EM-DAT, 2017). Bushfires represent 3.5% of these disasters. Wildfires are uncontrolled fires which occur frequently in dry and hot climate zones. These fires devastate big forest areas, destroy properties and kill many people. In 7th February 2009, also called Black Saturday, bushfires killed 173 people in Australia in the state of Victoria. The Australian government created a commission in order to understand why so many people died despite its effort to prepare people for bushfire events. The conclusion of the commission (Rhodes, 2014) was that the responsibility was shared between all the actors involved: emergency managers, firefighters, police and civilians. In case of fire, the Australian Fire Authorities Council advise residents to choose between two courses of action: "Prepare, Stay and Defend" their house from fires, or "Prepare and Leave Early". The emergency managers expected that civilians would follow instructions, prepare their fireplan and then apply it during the crisis. Despite the authorities' expectations, many civilians did not have a fire plan or they applied it too late waiting for a personalised message from emergency centres.

Multi-agent modelling and simulation has proved to be a useful tool for exploring "what-if" scenarios, emergency management strategies (Almeida et al.,2013; Chu et al., 2009; Dugdale et al. 2010; Thorp et al., 2006) and communication strategies (Adam et al., 2019; Mancheva et al., 2015; Sakellariou et al., 2008) for a

better understanding of the human behaviour in crisis and emergency situations.

The focus of our work is to provide a realistic simulation of bushfires and people's behaviours and interactions. Our goal is to provide a tool for emergency managers and stakeholders to allow them to explore different strategies and scenarios. To achieve our goal we have used a combination of different research approaches including multi-agent simulation, cognitive modelling and geospatial information representation.

In this paper we present our conceptual agent-based model of human behaviour and interactions in bushfires and its implementation. In the first section, we describe the state of the art concerning the research areas involved in our model. Then, we describe the theoretical foundations of our model and how it was constructed. We then show how this model was implemented and compare a 2D simple model and 3D GIS model in terms of processing time. We conclude with a summary and discussion about the model and our contributions.

STATE OF THE ART

We use an agent based modelling (ABM) approach to model and simulate human behaviour, and geographic information system (GIS) data to provide a more realistic environment.

ABM had been widely used for modelling and simulating human behaviour in different natural hazard situations such as earthquakes (Bangate et al.,2017), floods (Dawson et al., 2011), tsunamis (Mas et al., 2012) and bushfires (Adam et al., 2016; Minelli & Tonini, 2016; Thorp et al., 2006). ABM can capture emergent phenomena in complex systems, provide a natural description of such a system, and is flexible enough to model the micro and macro levels in a system (Bonabeau, 2002). Agents are defined by the following characteristics: (1) autonomy: each agent can control its own actions and its internal state; (2) heterogeneity: each agent can have its own specific set of attributes and behaviours; (3) social ability: agents can interact with each other via some kind of agent communication language (ACL); (4) bounded rationality: agents' knowledge is not universal but depends on their context; (5) reactivity: agents can perceive their environment (physical or abstract) and respond to the changes in it; (6) proactiveness: agents do not only perceive and act in their environment but exhibit goal-directed behavior (Wooldridge & Jennings, 1995; Crooks et al., 2018). These agents' characteristics show that ABM is an appropriate tool to model a complex system such as bushfires where different actors with heterogeneous behaviours interact with each other. Another way to model complex systems is to use equation based models. The advantage of using ABM instead of mathematical equations is that ABM can model entities with heterogeneous behaviour often with nonlinear relationships and with multiple interactions. For a complete discussion about ABM vs equation-based modelling see (Parunak et al. 1999).

There are several ways to model human behaviour in ABM, the simplest one is to use reactive agents whose behaviour is based on a perception - action loop. A more realistic and sophisticated approach is to use the BDI (*Belief, Desire, Intention*) (Rao & Georgeff,1991) cognitive model. This model is based on Michael Bratman's philosophical theory of action (Bratman, 1987). Human behaviour is described in terms of mental attitudes: *Beliefs, Desires and Intentions*. The *Beliefs* represent the knowledge that the agent has about the world (not necessarily true); the *Desires* represent the actions that agent would like to do in the future; and the *Intentions* are the chosen actions that will allow the agent to accomplish its goals. It is possible that the agent has different plans to achieve the same *Intention.* In this case, if one of the plans fails, another one will be selected. For (Adam et al., 2016), BDI is a more appropriate approach for modelling human behaviour in crisis situations involving complex decision making, influenced by emotions and by the social context than reactive agents.

Another important issue that should be considered when modelling human behaviour in emergency situations, is communication. Modelling communications allows us to implement a realistic spread of the information between different actors. Communication is a social interaction and can be viewed as a complex system where entities, e.g. humans, interact using a common language. Different standards for Agents Communication Language (ACL) exist, we have chosen to use FIPA (Foundation for Intelligent Physical Agents) - ACL (Fipa, A.C.L., 2002) that is widely adopted in ABM. Based on its theoretical foundations FIPA-ACL can be easily integrated into a BDI agent architecture. For example, (Mancheva et al., 2015) used FIPA and BDI to model the communications in a medical team during cardiopulmonary resuscitation. In ABM of bushfires (Sakellariou et al., 2008) used FIPA-ACL and BDI to model firefighters cooperation for extinguishing forest fires. Also (Adam et al., 2019) used BDI agents and created their own framework for agent's communication in order to study the best ways for information spreading concerning bushfires.

(Wise, 2014) argues that combining GIS and ABM allows researchers to gain better insight into how a crisis may develop and to explore how boundedly rational individuals behave in a complex physical environment. There are several examples of models combining GIS and ABM, for a complete review see (Crooks et al., 2018). Here we are interested in how ABM and GIS have been used in bushfires. (Minelli & Tonini, 2016) designed an ABM that simulated alpine forest fires, urban traffic and firefighters using GIS data. (Thorp et al.,

2006) also used ABM and GIS to model wildfires, traffic simulation and evacuation in Santa Fe, USA. Although these models provide good frameworks to study fire spreading, traffic simulation and evacuation in a geospatial environment, they do not provide any fine grained behaviour model of different actors in such a situation. On the contrary (Adam et al., 2016; Adam et al, 2017) created a detailed cognitive model of civilian behaviour in bushfires and simulated it using ABM, but they did not use GIS data.

This paper describes a unified framework for simulating realistic crisis situation scenarios. To our knowledge, there is no research study that has simultaneously employed detailed cognitive modelling of different actors in bushfire situations, using an advanced language for communication based on speech act theory, and integrating spatio-temporal information.

CONCEPTUAL MODEL

The model is inspired by a body of work modelling the human behaviour in bushfires (Adam et al., 2016; Adam et al. 2017; Adam et al. 2019). The model has been designed based on the data from witness statements (Exell, 2009) of people who survived the 2009 Black Saturday fires in Victoria, Australia. These witness statements provide realistic data of how civilians responded to bushfires. We have manually analysed the 100 witnesses' interviews to help to construct the model, and also used statistics about the victims (Teague et al., 2009), for example:

- Causes of death: 14% died while escaping (4% by car and 10 % by foot); 69% died while passively sheltering in a building; 17% died trying to defend their house.
- Preparation: 58% of victims had made no preparation to their property or themselves; 20% intended to stay and defend their property and were well prepared.
- Awareness: of those who died, 30% were taken by surprise, 38% did not have any knowledge about what to do.

System Specification

The architecture of the model is shown in Figure 1. For the sake of readability, we have removed all attributes and methods of simple reactive agents and have kept only BDI agents definitions. We have defined 3 abstract types of agents: WeatherAgents, LandAgents and GameAgents.

Weather agents

Fire

Since the focus of our work is on modelling human behaviour in bushfires, we did not use a complex fire spreading model, as done in other studies (Duff et al., 2013). The fire starts at a random time (measured in simulation cycles), and location at the beginning of the simulation; simultaneous fires are also possible. Fire has different attributes such as damage radius, heat radius and intensity. The intensity is the fire strength of damaging buildings within a damage radius. The heat radius represents the radiant heat around the fire that injures civilians. At each simulation step, based on a probability, the fire can grow by increasing its intensity, propagate in a radius, emit embers, injure civilians and damage buildings. It can also stop burning when extinguished by firefighters, by modifying its intensity to null.

Forecast

The Forecast agent has the role of observing fires and displaying different fire danger ratings as a function of the number of fires and their intensity. The ratings include: low, high and severe state. Different agents (e.g. civilian, emergency managers) can check the Forecast agent's danger ratings at any time.

LandAgents

LandAgents include all landscape agents: roads, buildings, water areas and forests. The LandAgents are created from real geospatial data. The processing of the GIS data is explained in the Implementation section. The number, location and shape of roads, water areas, forests and buildings depend on this data.

Roads

The roads are represented by a graph. This road network is used by agents (e.g. civilian, police and firefighters) driving a car or a truck. A road could be blocked by a fire or by the police. In future versions, we would like to

calculate a speed coefficient (as a function of the road capacity and width) that will decrease the speed of driving agents, simulating traffic jams.

Water Area

Water areas are used for recharging fire truck water containers. Since the available quantity of water in these areas is huge, we simplify and consider it to be unlimited for now. In the future versions, water areas can be used as shelters for civilians, as noted in witness statements.

Forest

The forest has attributes describing its density, dryness and height.

Obstacles

The obstacles are an abstract class of agents that gathers all non-human agents that could block the movement of human agents (e.g. civilian, firefighter and police). We have implemented a mechanism so that agents avoid buildings and fires.

Building

Three types of buildings are modelled: house, shelter and base (for police or firefighter agents). All buildings have a fire resistance level. For shelters and bases this resistance is set to maximum, they cannot be destroyed. Agents inside shelters and bases cannot be injured by the fire. A house can have zero or one occupant. This choice was done for model simplicity, since including family interactions can significantly increase the model complexity. Houses have some initial resistance that can be increased if the owner decides to prepare it (e.g. remove fuels and garden furniture, put sprinklers on). When the resistance drops to 0, the house collapses (shown in black in the simulation view). If the owner is in or close to the house, the collapse will remove his plans to shelter in the house or to defend it.

GameAgents

GameAgents have common characteristics like speed, perception radius (auditory and visual), list of fires, and ability to communicate. The agent's speed depends on the agent's mean of transport (e.g. by car/fire truck or by foot). The perception radius represents the area around the agent where it can "see" and "hear" other agents (e.g. civilians, fire, buildings, etc.). The list of fires contains the perceived fires by the agent in its perception radius. Note that, even if some of the fires are extinguished, the agent will continue to believe that a fire exists at a certain location until it perceives that there is no longer a fire at that location. All GameAgents are implemented with a BDI architecture.

Helicopters

Helicopters search for fires and report their coordinates to emergency managers. For simplicity's sake, the helicopter agents are basic and do not extinguish fires. At the beginning of the simulation helicopters are located at their base and once they receive an order from an authority agent, they start to search for fires. If they perceive a new fire in their perception radius, they will report its location to the authority agent. Helicopters continue to search for fires until the end of the simulation, when all fires stop.

Police

According to the witness statements, the Australian police has the role of informing people and blocking roads to prevent citizens from moving towards a fire. At the beginning of the simulation, police agents are located in their base. They can go to a specific road location when requested to do so by the authority agent, moving only by car on the road network. The police agents can inform the authority agent about newly perceived fires, or inform civilians about further fires on the road.

Authority

To simplify, we have decided to model the emergency manager's behaviour and the authority's behaviour into one single abstract agent that we call Authority. The Authority agent has two main goals: extinguish fires and save residents. At the beginning of the simulation, the Authority agent observes the forecast provided by the Forecast agent. If the fire danger level is high, it can decide to achieve its goals with plans among the following:

- Get global information about the fire location: by requesting helicopters to fly over specific areas
- Get local information about fire location: by requesting the police to go to strategic road network hubs
- Deploy firefighters trucks to fire locations: by managing busy or available firefighters and active fires locations
- Broadcast emergency evacuation alert to civilians

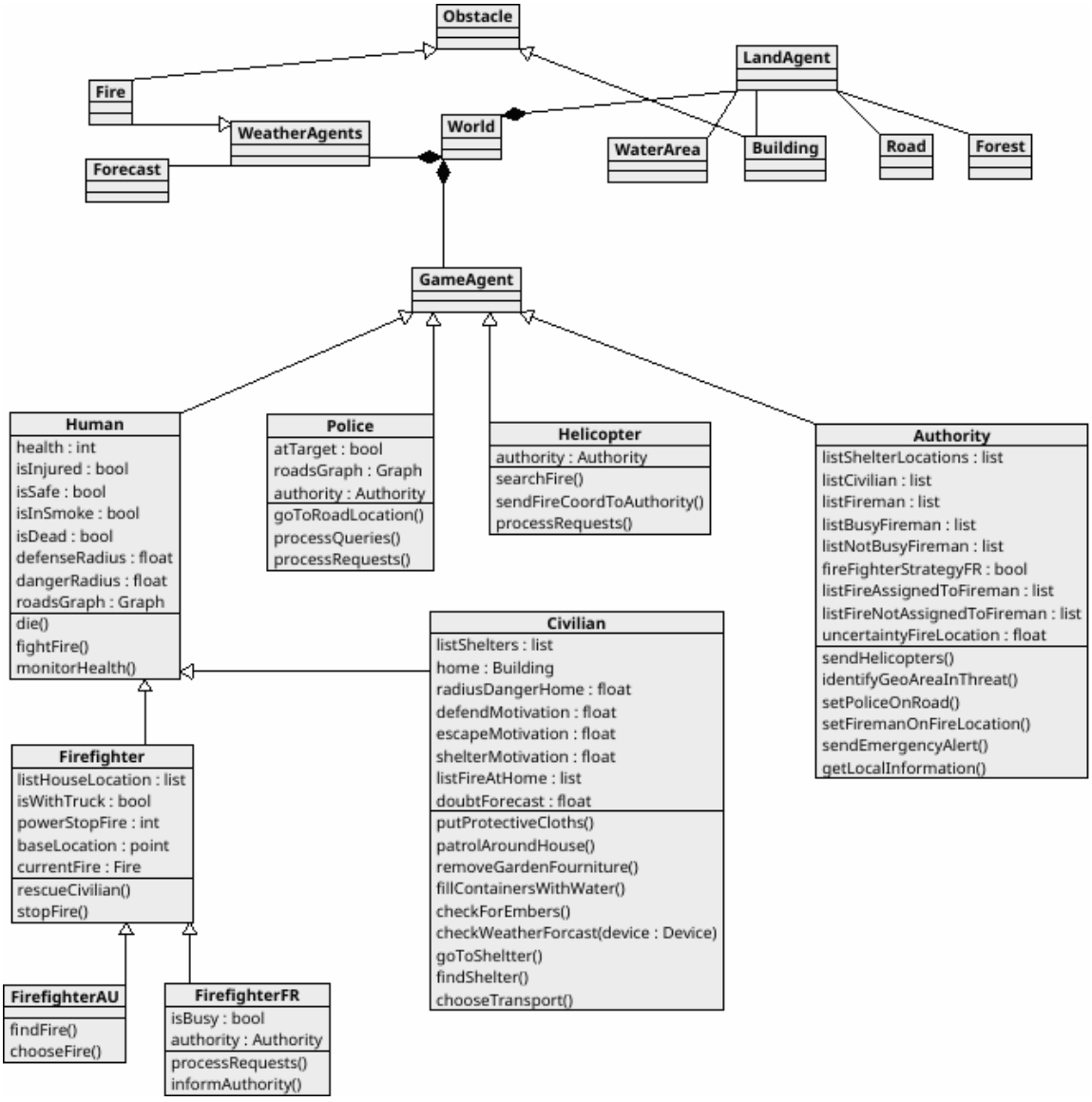


Figure 1. Simplified UML class diagram of the model

Firefighter

In our model the firefighters have 2 main goals: extinguish fires and save civilians. The firefighter's priority is always to save people's lives even if there is a nearby intense fire[1]. In the introduction we stated our goal of providing a tool for testing emergency management strategies. Firefighters in different countries have different protocols and strategies when they extinguish fires. We have decided to model and implement both the Australian and French firefighter's strategies. From interviews, we know that Australian firefighters work in a decentralized manner, going from one fire to another. Conversely, French firefighter management is more centralized. French firefighters are given orders to go and extinguish a fire at a specific location and when the fire is under control, they go back to their base and wait for new orders. Depending on a boolean parameter, the firefighters in our simulation apply either the Australian or French strategy. In both cases at the start of the simulation, the firefighters are located at their base. French firefighters receive orders from the Authority agent to go to a specific location and extinguish a fire. Once the fire is stopped they go back to their base and inform the authority that they are available and that the fire on that location is stopped. Australian firefighters listen to the forecast and when they believe that there is fire danger, they start to search for fires. When they stop a fire, they search for another one. Firefighters move on the road network driving fire trucks at a random speed. The fire truck has limited water capacity and when the water is used, firefighters refill with water at the closest water area. At any time during the simulation, if firefighters perceive an injured civilian, they will put on hold all other

[1] Source: private communication with French firefighter, requesting anonymity.

plans and will attend to the injured civilian. Once the civilian has been attended to, it is removed from the simulation; this represents the idea that the civilian has been driven to hospital or a safe area.

Civilian

Our model uses data of civilians that survived the Australian bushfires. Residents have to choose between two fire plans: "Prepare, Stay and Defend" or "Prepare and Leave Early"[2]. In our model, civilians can either defend their house, leave it or passively shelter in the house depending on a motivation parameter. At the beginning of the simulation, civilians are located in their houses or they move (by car or by foot) around their environment. There are 2 ways for a civilian to believe that there is fire danger: either they perceive a fire in their perception radius or they receive an evacuation alert from the Authority agent. If a civilian knows that there is fire danger, he will activate his fire plan to stay, to go or to passively shelter in his house. Civilians can escape by foot or by car depending on a probability parameter, set from the statistics shown in the beginning of this section. Civilians can go to a shelter selected among their known shelters list. If the civilian decides to defend his property, he can choose first to prepare his property and/or himself. To defend his property, the civilian goes around his house within a protection radius and searches for fires and embers. Beyond a danger threshold based on the number of fires around his house, the civilian may decide to shelter inside until the end of the simulation or go to a shelter.

Communication model

We model agent's communications with FIPA-ACL (Fipa, 2002). FIPA-ACL is based on speech act theory (Searle, 1969) that considers an utterance as having a performative function in language and communication. Based on that theory, exchanging information (receiving/sending a message) is an action in our model. A FIPA message has several parameters; we have simplified the message structure as follows: type, sender, receiver and content. FIPA specification defines 22 communicative acts. From witness statements and based on our agent BDI model's constraints, we have chosen to use the following 3 acts:

- **inform-ref**: the sender informs the receiver for an object description.
- **query-ref:** ask another agent for a referred object value (e.g. fire location).
- **request:** the sender requests the receiver to perform some action (e.g. go to fire location).

Here are some examples of messages exchanged between two agents in our model:

request (authority, police, [GO_TO: {125; 456; 852}]): the authority agent requests a police agent to go to road location with coordinates {125; 456; 852}

inform-ref (helicopter, authority, [FIRE_LOCATION: {863; 15; 335}]): the helicopter agent informs the authority about a fire perceived at coordinates {863; 15; 335}

query-ref (authority**,** police, [FIRE_LOCATION]): the authority agent queries the police if the police knows of a new fire location

We will demonstrate in the next section how we have implemented these specifications into the agent's BDI model.

Dynamic model

We have used the Tactics Development Framework (TDF) to design the dynamic specifications (Evertsz et al., 2014) of all cognitive agents in our simulation. This methodology has already been used for crisis situations and has proven its utility in other studies modelling human behaviour in bushfires (Adam et al., 2016). The TDF methodology is composed of 3 phases: (1) *System specification:* definition of goals, scenarios, percepts, actions, data, actors and roles; (2) *Architectural design*: specification of agent's interactions (via protocols) and messages; (3) *Detailed design:* detailed agent plan diagrams including subgoals, internal messages and actions. Here we will describe the architectural design and the detailed design of our model.

Architectural design

In the architectural design we have specified all agent interactions that can occur during the simulation. Figure 2 shows a detailed view of all possible messages between different agents as well as their contents. We have used the formalism defined in the previous section. Each colored square in Figure 2 represents the communications for a specific agent and the directed arrows - the receiver agent. For example we can see that the Civilian agent can send messages to the Authority agent, the police, the firefighters and to the other civilians.

[2] Hereafter referred as 'stay' or 'go' plan

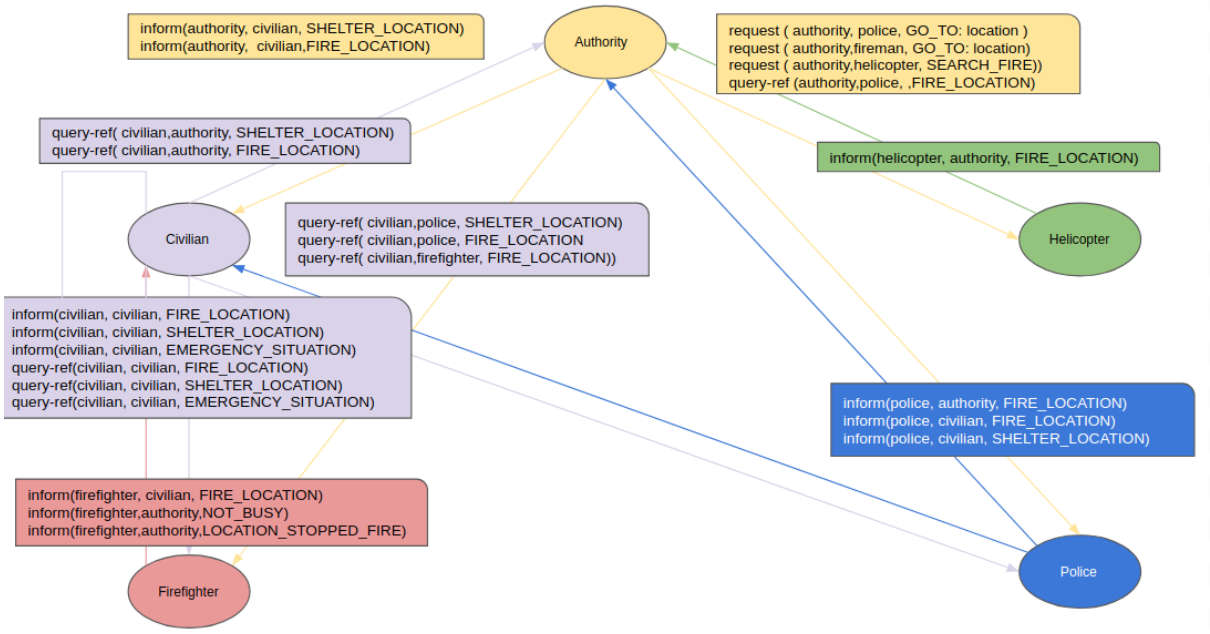


Figure 2. Architectural design: specification of agents' interactions

Detailed design

The detailed diagrams are very useful for the modeller since they allow making a direct link between the agent's goals and its BDI specifications and implementation. Due to space limitations we will only show a detailed diagram of authority agent goals.

Authority

Figure 3 details the authority subgoals and plans of the Stop Fire goal. The Stop Fire goal is activated when the authority agent believes that there is fire danger provided by Forecast agent. To stop the fire the authority agent has to know where the fire is and then deploy firefighters to that location. The authority agent can also deploy police agents at strategic road locations in order to inform residents. We split the Stop Fire goal into 2 sub-goals Get fire information and Set emergency service on road. Get fire information goal is achieved by applying 2 plans Get global information and Get local information. Get local information is executed under certain conditions: police have to be already deployed on the road network, and the authority's uncertainty level about the fire location should exceed a fixed threshold. This threshold increases with each simulation step and decreases when the authority agent receives fire location information. Using the threshold condition means that we can model in a realistic way several calls of Get local information plan. This plan consists of one action, the authority queries the police if it knows about new fire locations. As we explained in the previous section, we consider a communication as an action. As in real life, when an emergency manager is uncertain about the fire location, he will call the services located on-site. Set emergency service on road is split into 2 plans: Deploy firefighter on road and Deploy police on road. The Deploy firefighter on road plan will be called only if the authority is managing French firefighters and if the list of active fires is not empty. In this case, the authority agent has to optimise the deployment of firefighters resources to specific fire locations.

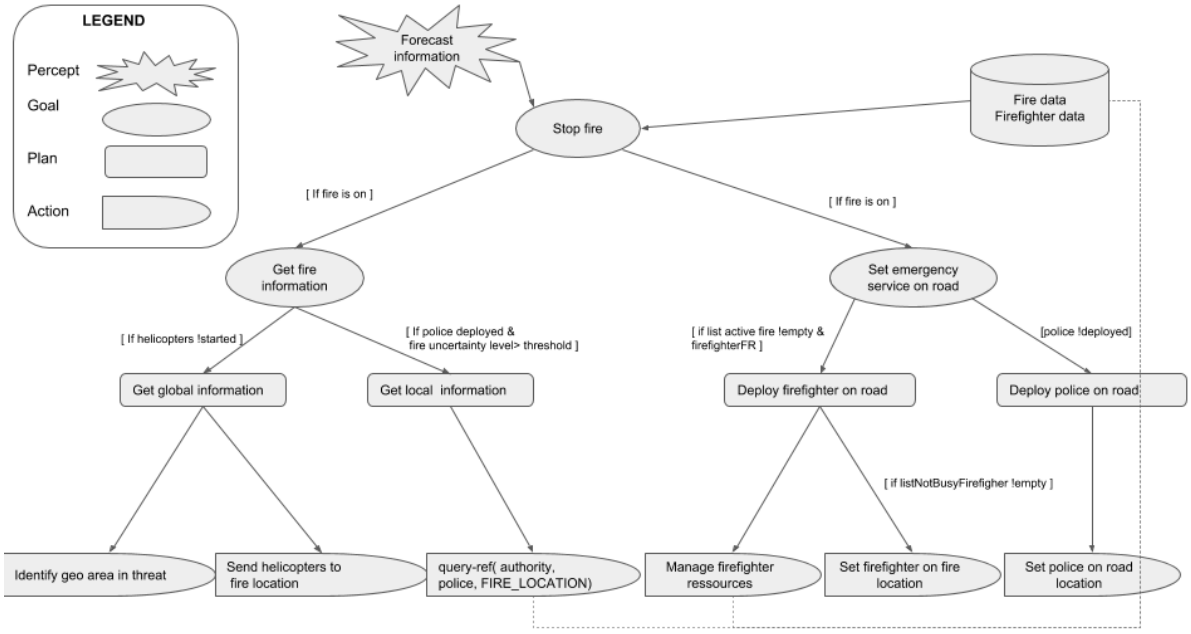


Figure 3 . Detailed design: Diagram of authority agent Stop fire goal.

IMPLEMENTATION OF THE MODEL

Many agent based simulation platforms exist; for a review and comparison see (Kravari & Bassiliades, 2015). We have used the GAMA platform (Grignard et al., 2013) for implementing our model. GAMA is an open source modelling and simulation development environment for building spatial agent-based simulations. GAMA uses a meta agent oriented programming language called GAML. GAMA combines GIS data and 2D/3D visualisation and supports the implementation of large scale models. It also includes a BDI plugin that allows modellers to easily implement BDI agents, and it is FIPA-compliant. All these characteristics fit very well with the requirements of our model.

Agent's world

The agent's world can be built in 1 of 2 different alternative ways: (1) 2D model; (2) 3D GIS model. All agents in our model are world-agnostic, meaning that they have a generic implementation independent of the world's specifications. This allows us to use different environment visualisations, setups and different maps. At the beginning of the simulation, in the GUI view, we can select between the 2 different models.

2D model

The 2D model has simpler view and smaller dimensions than the real 3D geospatial model, allowing us to see small agents without zooming (e.g. civilian are 2m high). Figure 4 is a 2D model screenshot. All agents are generated at random locations. The map represents roads graph network, painted in pink. We can see small fires close to some houses and civilians 'defending' them. On the bottom right side, firefighters are leaving their base (green square) and driving towards fires.

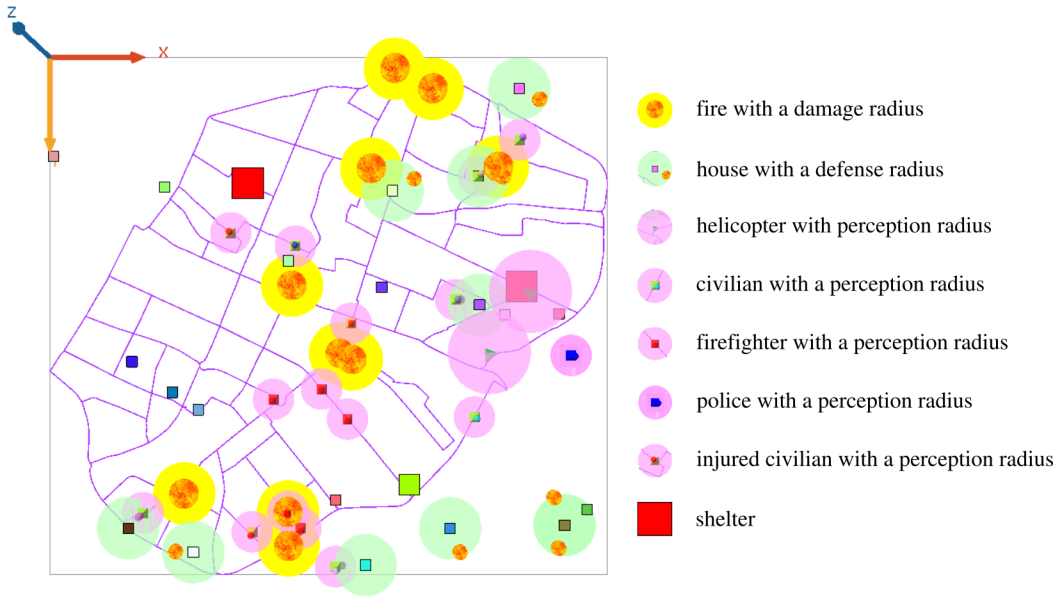


Figure 4. 2D model screenshot at cycle 17 since the beginning of the simulation

3D geospatial model

GIS data can be easily integrated into the agent model by providing shapefiles[3] that specify different geographical objects. Non-human agents, such as forests, buildings, roads and water areas, are created from these shapefiles. We have used OpenStreetMap[4] for obtaining GIS data and then GAMA to process and save them into shapefiles. We used also QGIS[5] to change the shapefiles spatial reference system to the corresponding Australian one, GDA94[6]. We model the Kinglake city area, in Victoria, because its was one of the most affected cities during Black Saturday. Figure 5 shows a screenshot of the simulation using the GIS data of Kinglake city; we can see the same agents and colours but with a different layout. Although buildings, fires and road network are visible, we cannot see civilians, firefighters and police since their size is too small at this scale. The green area represents the forest.

BDI implementation

GAMA provides a BDI plugin (Taillandier et al, 2016) to create BDI agents with the GAML language. A BDI agent has a plan library and 3 different databases for beliefs, desires and intentions. An engine updates these based on the agent's perceptions of its environment and its internal rules. In GAML, a specific type called predicate is used to describe the domain ontology. Here is a code snippet giving an example of predicate definition.

```
predicate get_local_info_fire <- new_predicate ("get local info fire");
predicate set_emergency_service_police <- new_predicate ("set emergency service police");
```

Below is an example of an authority agent rule that generates the desire to get local information about fires only when it believes that the police are deployed on the road and when its uncertainty level exceeds a threshold. This example shows part of the implementation of the conceptual model described in Figure 3.

[3] A shapefile is a widely used geospatial vector data format for GIS.
[4] OpenStreetMap is a free editable map of the world, created by volunteers, https://www.openstreetmap.org
[5] QGIS is an open-source platform for GIS data processing.
[6] GDA94 is Geocentric Datum of Australia 1994

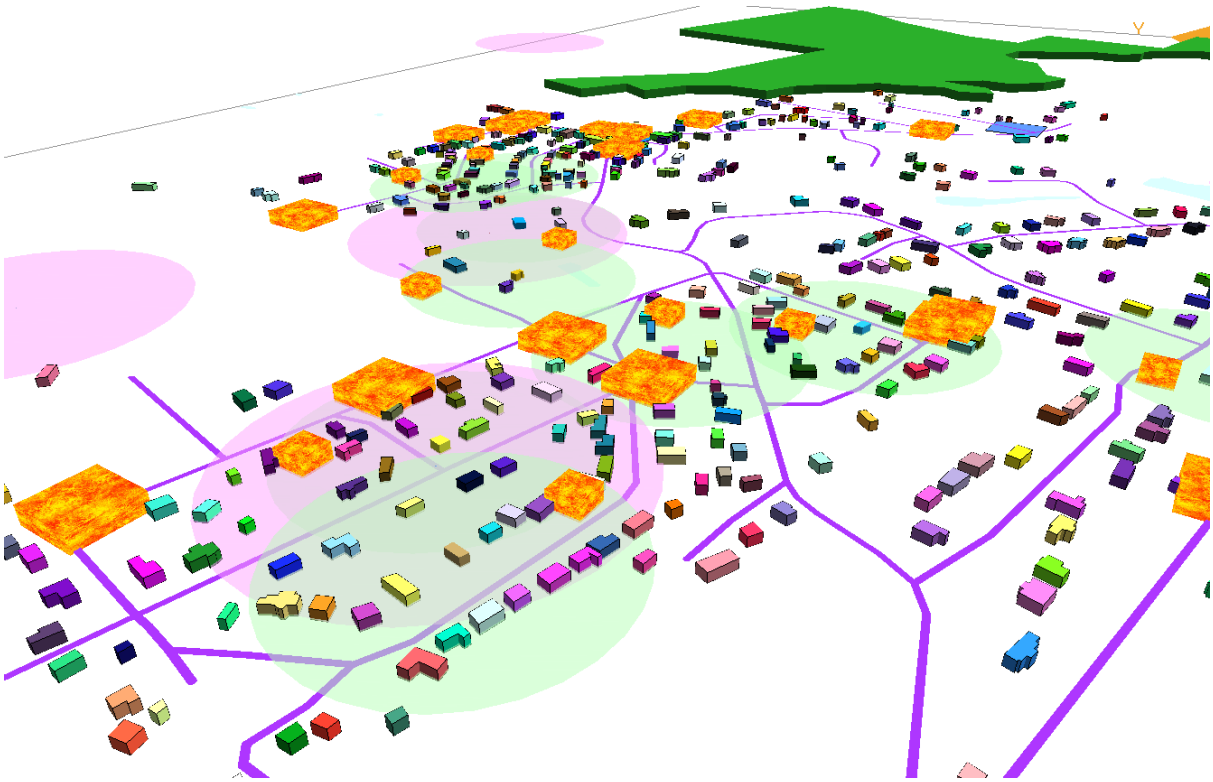


Figure 5. 3D model screenshot of Kinglake city in Victoria state, Australia, representing 4000m x 3000m map

```
rule when: has_belief(set_emergency_service_police) and uncertainLocationFire > 0.7 new_desire:
get_local_info_fire ;
```

BDI agents also have a library of plans for achieving their intentions. For instance, the following plan accomplishes the get_local_info_fire intention by calling the action queryPolice.

```
plan getLocalInfoFire intention: get_local_info_fire {
    do queryPolice;
}
```

In that action, the authority agent queries each Police agent, one by one about the fire location. Since, it knows that it will receive the fire location information, the uncertainty threshold decreases to 0, so the next simulation step the rule presented earlier won't be executed. Adding the belief of getting the local information will remove the get_local_info_fire intention from the intention stack.

```
action queryPolice {
        loop p over:list (Police) {
do start_conversation to: [p] protocol: 'no-protocol' performative: 'query' contents: [ (
FIRE_LOCATION )] ;
    }
        uncertainLocationFire <- 0.0;
        do add_belief(get_local_info_fire); }
```

FIPA implementation

In GAMA, if an agent is specified with a FIPA capability, it is provided with embedded actions and lists that hold different FIPA communicative acts and communications. Below are GAMA examples of the speech acts that we model:

```
do start_conversation to: [a] protocol: 'no-protocol' performative: 'inform' contents: [ ( msg )] ;
do start_conversation to: [a] protocol: 'no-protocol' performative: 'query' contents: [ ( msg )] ;
do start_conversation to: [a] protocol: 'no-protocol' performative: 'request' contents: [ ( msg )] ;
```

In the action queryPolice, the authority agent individually queries police agents about the fire location. GAMA also provides default lists for receiving different messages: informs, queries and requests lists. However, the modeller has to specify the message processing in different lists. Here is a code snippet of agent reflex[7] reading its list of informs messages:

```
reflex readInforms when:!empty(informs) {
        loop i over: informs {
                string msgContent <- string(i.contents);
..... }
}
```

PRELIMINARY RESULTS

Below are some preliminary results. We have compared the processing time (in minutes) between the 2 models with different scenarios (Table 1). We ran 5 simulations per scenario, varying just one parameter at a time; the remaining parameters did not vary between simulations. We have chosen to stop the simulation at 500 cycles in order to avoid waiting until all fires have been extinguished. We examined how the number of BDI agents and reactive agents affect the model performance for both the 2D and 3D model. We have chosen Civilian agents to represent BDI agents and Fire agents to represent the reactive agents in the model comparison.

Table 1. Simulation Experiments

	2D model	3D model
Scenario 1	20 Civilians & 5 Fires	20 Civilians & 5 Fires
Scenario 2	100 Civilians & 5 Fires	100 Civilians & 5 Fires
Scenario 3	20 Civilians & 100 Fires	20 Civilians & 100 Fires

Figure 6 shows the probability density function of the simulation duration for the different scenarios in Table 1. We verified the effect of increasing the number of reactive agents (from 5 Fires to 100 Fires) by comparing the processing times in 2D model Scenario 1 (the green bell on Figure 6) and Scenario 3 (ocher bell) (t-test p-value = 0.26 > 0.05) as well as in the 3D model Scenario 1 (pink bell) and Scenario 3 (blue bell) (t-test p-value = 0.21 > 0.05). We can see from t-test results, that that is no significant difference in processing times for 2D and 3D models when we increase the number of reactive agents (Fires). We have then verified the effect of increasing the number of BDI agents (from 20 civilian to 100 civilian) by comparing the Scenario 1 (green bell for 2D; pink for 3D) and Scenario 2 (orange bell for 2D; cyan for 3D) and we found that there is significant difference in the processing times (2D model t-test p-value = 0.00003 < 0.05; 3D model t-test p-value = 0.0002< 0.05). We have compared Scenario 1, 2, 3 for 2D and 3D model, and we have found a significant difference in processing times between both models, indicating that GIS data display and processing is time consuming.

[7] A method that is called each simulation step

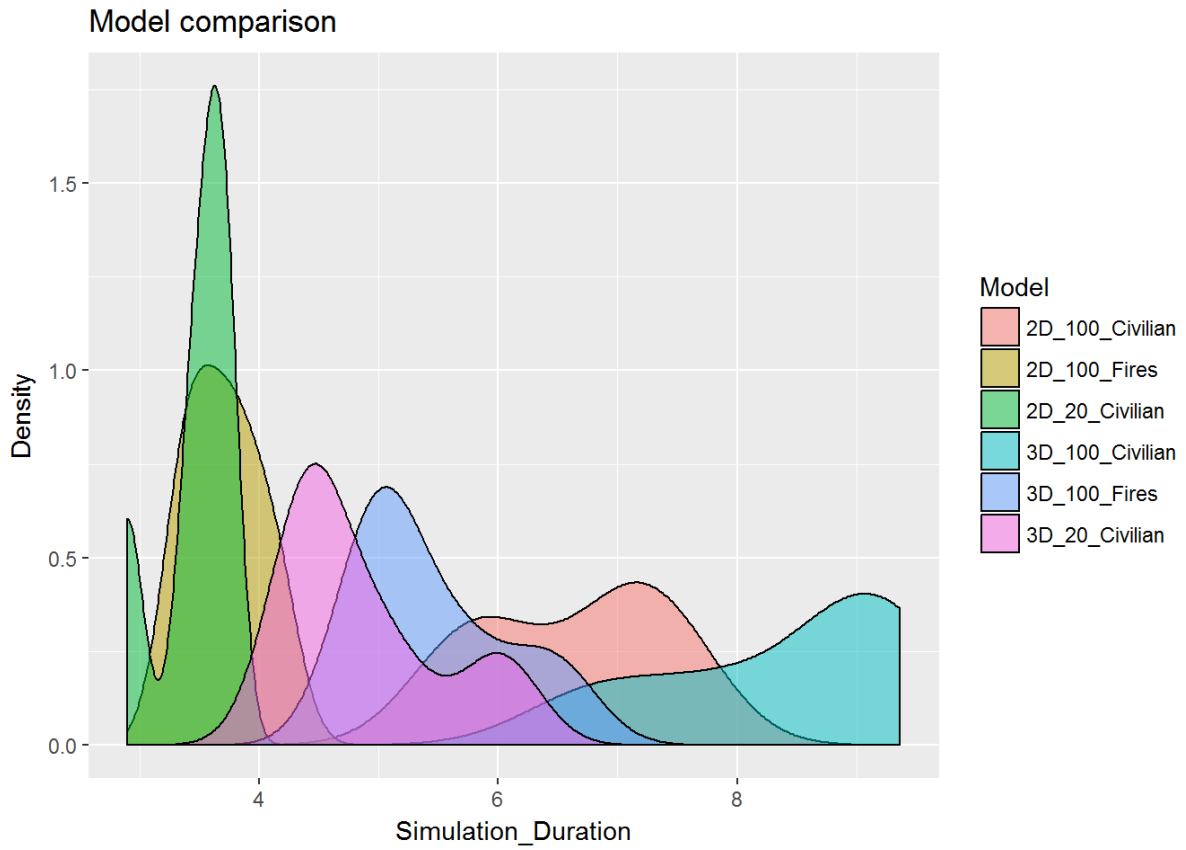


Figure 6. Comparison of the 2D and 3D model processing time (in minutes)

CONCLUSION

The goal of our work was to present a unified framework for modelling a complex crisis situation such as the human behaviours and interactions in bushfires. We proposed agent-based model including BDI cognitive modelling combined with the FIPA standard for communications, and a GIS for modelling a realistic environment which to our knowledge has not yet been done before. We described how we built our conceptual model using UML and TDF and how the model was implemented using the GAMA agent-based platform. We also demonstrated the flexibility of our model showing that the same agents' implementation can be represented in a 2D simple model or a 3D GIS model. The preliminary results showed that a 3D GIS model takes significantly more processing time than the 2D simplified model and that increasing the number of BDI agents also significantly affects the processing time. This constrains the modeller to make a fair trade off between the model complexity and realism in the agent's design. In this paper, we have presented the first preliminary results and in the future work we need to do internal and external validation of the model.

In future work, we will explore the model's parameters space and perform a sensitivity analysis. The model will then be validated by comparing the model's results to the statistical observations reported by (Teague et al., 2009). Once the model is validated, we would like to examine different scenarios. For example, to assess the Australian and French firefighter strategies in different fire configurations (e.g. concentration of the fire at one location/more locations and in function of the distance between fires) in order to determine which strategy is more appropriated to which scenario. We can also test different emergency manager strategies for the management of the available firefighters (e.g. is it better to extinguish first fires with big fire spread or with big intensity?) or for the police locations (at which road location, the police will inform more civilian about the fire situation). This realistic model will allow emergency managers and stakeholders to get valid results transferable to real life situations. We then wish to modify the model into a serious game for emergency situation training.

ACKNOWLEDGMENTS

This research was funded by the University Grenoble-Alpes through AGIR project SWIFT (2016-2019). We would like to thank Patrick Taillandier for providing us a GAMA script for GIS data processing and Jérémie Glossy for participating in the GIS data processing.

REFERENCES

Adam C. , Bailly C. & Dugdale J.. Communication During Bushfires, Towards a Serious Game for a Serious Matter. International Journal of Information Systems for Crisis Response and Management (IJISCRAM). Volume 10, Issue 2, edited by Bañuls Silvera. 2019 (in press).

Adam C., Taillandier F., Delay E. , Plattard O., Toumi M.. SPRITE – participatory simulation for raising awareness about coastal flood risk on the Oleron island. ISCRAM-med 2016. In: Díaz P., Bellamine Ben Saoud N., Dugdale J., Hanachi C. (eds) Information Systems for Crisis Response and Management in Mediterranean Countries. ISCRAM-med 2016. Lecture Notes in Business Information Processing, vol 265. Springer, Cham.

Adam C. , Taillandier P., Dugdale J. and Gaudou B.. BDI vs FSM Agents in Social Simulations for Raising Awareness in Disasters. International Journal of Information Systems for Crisis Response and Management (IJISCRAM). Eds: Dugdale, Gonzalez and Turroff. Vol 9 issue 1, 2017.

Adam C., Gaudou B.. BDI agents in social simulations: a survey. In: Knowledge Engineering Review. Volume 31(3), June 2016, pp. 207-238.

Adam C., Danet G., Thangarajah J. & Dugdale J. . BDI modelling and simulation of human behaviours in bushfires. ISCRAM-med 2016.

Almeida J.E. , Rosseti R.J.F. , Coelho A.L . 2013 Crowd simulation modeling applied to emergency and evacuation simulations using multi-agent systems DSIE'11 - 6th Doctoral Symposium on Informatics Engineering (pp. 93-104). Engineering Faculty of Porto University, Porto.

Bañgate J., Dugdale J., Beck E. and Adam C.. SOLACE: a multi-agent model of human behaviour driven by social attachment during seismic crisis. In: International Conference on Information and Communication Technologies for Disaster Management (ICT-DM'2017), Münster, Germany, 11-13 December 2017.

Bonabeau E. "Agent-based modeling: Methods and techniques for simulating human systems," Proceedings of the National Academy of Sciences, vol. 99, no. 3, pp. 7280–7287, 2002.

Bratman M. E. , Intention, Plans, and Practical Reason. CSLI Publications, 1987.

Chu, T.Q., Drogoul, A., Boucher, A. and Zucker, J.D., 2009. Interactive learning of independent experts' criteria for rescue simulations. J. UCS, 15(13), pp.2701-2725.

Crooks, A.T., Heppenstall, A. and Malleson, N. (2018), Agent-based Modelling, in Huang, B. (ed), Comprehensive Geographic Information Systems, Elsevier, Oxford, England. Volume 1, pp. 218-243

Dugdale J. , Bellamine-Ben Saoud N., Pavard B. and Pallamin N.. Simulation and Emergency Management. In Information Systems for Emergency Management. Series: Advances in Management Information Systems. (2010) Editors: B. Van de Walle, M. Turoff and S.R. Hiltz. Publishers: Sharp.

Dawson, R. J., Peppe, R., & Wang, M. (2011). An agent-based model for risk-based flood incident management. Natural hazards, 59(1), 167-189.

Duff, T.J., Chong, D.M. and Tolhurst, K.G., 2013. Quantifying spatio-temporal differences between fire shapes: Estimating fire travel paths for the improvement of dynamic spread models. Environmental modelling & software, 46, pp.33-43.

Exell S., "Witness statements," http://vol4.royalcommission.vic.gov.au/ index03a1.html?pid=111.

EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium. https://www.unisdr.org/we/inform/publications/61119

Evertsz, R., Thangarajah, J., Yadav, N. and Li, T., 2014, May. Tactics development framework. In Proceedings of the 2014 international conference on Autonomous agents and multi-agent systems (pp. 1639-1640). International Foundation for Autonomous Agents and Multiagent Systems.

Fipa, A.C.L., 2002. Fipa acl message structure specification. Foundation for Intelligent Physical Agents, http://www. fipa. org/specs/fipa00061/SC00061G. html (30.6. 2004).

A. Grignard, P. Taillandier, B. Gaudou, D-A. Vo, N-Q. Huynh, A. Drogoul (2013), GAMA 1.6: Advancing the Art of Complex Agent-Based Modeling and Simulation. In 'PRIMA 2013: Principles and Practice of Multi-Agent Systems', Lecture Notes in Computer Science, Vol. 8291, Springer, pp. 117-131.

Kravari, K. and Bassiliades, N., 2015. A survey of agent platforms. Journal of Artificial Societies and Social Simulation, 18(1), p.11.

Mas, E., Suppasri, A., Imamura, F., & Koshimura, S. (2012). Agent-based simulation of the 2011 great east japan earthquake/tsunami evacuation: An integrated model of tsunami inundation and evacuation. Journal of Natural Disaster Science, 34(1), 41-57.

Minelli A, Tonini M. 2016. An agent-based model to assess the forest fires dynamic in the southern Swiss alpine region. PeerJ Preprints

Parunak, V.D., H., Savit, R., Riolo, RL, 1999. Agent-based modeling vs equation-based modeling: a case study and users' guide. Proceedings of Multi-Agent Systems and Agent-Based Simulation, LNAI Series, 1534, p.10.

Rao A. & Georgeff M., "Modeling rational agents within a BDI architecture," in 2nd International Conference on Principles of Knowledge Representation and Reasoning, 1991, pp. 473–484.

Rhodes A., "Why don't they do what we think they should?" in AFAC. Emergency Management Victoria, 2014

Sakellariou I., Kefalas P., Stamatopoulou I. (2008) Enhancing NetLogo to Simulate BDI Communicating Agents. In: Darzentas J., Vouros G.A., Vosinakis S., Arnellos A. (eds) Artificial Intelligence: Theories, Models and Applications. SETN 2008. Lecture Notes in Computer Science, vol 5138. Springer, Berlin, Heidelberg

Searle, J.R. (1969). Speech Acts. Cambridge University Press, Cambridge, UK

Taillandier, P., Bourgais, M., Caillou, P., Adam, C. & Gaudou, B. A situated BDI agent architecture for the GAMA modelling and simulation platform. (2016) In: International Workshop on Multi-Agent-Based Simulation (MABS 2016) at AAMAS 2016, 9 May 2016 - 10 May 2016 (Singapore, Singapore).

Teague B. ,McLeod R. , and Pascoe S. , "Final Report, Volume I, Part 2: The people who died. Chapter 21: lessons learnt." 2009 Victorian Bushfires Royal Commission, Tech. Rep., 2009. [Online]. Available: http://goo.gl/0xcUFG

Thorp, J., Guerin, S., Wimberly, F., Rossbach, M., Densmore, O., Agar, M. and Roberts, D., 2006. Santa Fe on fire: agent-based modelling of wildfire evacuation. In Proceedings of the Agent 2006 Conference on Social Agents: Results and Prospects, Chicago, IL.

Wise, S. (2014) Agent-Based Modeling and GIS: Exploring Our New Tools in a Disaster Context. In: (Proceedings) GISRUK 2014, 22nd GIS Research UK Conference, 16 - 18 April 2014, Glasgow, UK.

Wooldridge, M. and Jennings, N.R., 1995. Intelligent agents: Theory and practice. The knowledge engineering review, 10(2), pp.115-152.

Data Acquisition for Ad-Hoc Evacuation Simulations of Public Buildings

Ingo J. Timm *
Center for Informatics Research and Technology – Trier University†
itimm@uni-trier.de

Bernhard Hess
Center for Informatics Research and Technology – Trier University

Fabian Lorig
Center for Informatics Research and Technology – Trier University

ABSTRACT

Crowd simulation is suitable to evaluate evacuation strategies but its validity strongly depends on the quality of input data. The acquisition of adequate input data is particularly challenging when simulating the evacuation of public buildings such as universities. As they are publicly accessible, the exact number of persons on site is unknown. Yet, to investigate specific emergency situations by means of simulation, e.g. amok or fire, information is required about distribution and amount of people within the building at a specific point of time. Due to data privacy, public buildings do not implement access control. However, data artifacts are available in various information systems, e.g., wifi data, room administration. Our hypothesis is, that the acquisition and fusion of such data artifacts is sufficient to enable data-based ad-hoc simulation of evacuation scenarios as decision support for the operations management. To this end, we introduce a procedure for the situation-dependent collection fusion of simulation input data. Furthermore, a case study is provided to demonstrate the feasibility of the approach.

Keywords

Evacuation of Public Buildings, Data Fusion, Data Aggregation, Crowd Simulation, Social Simulation

INTRODUCTION

In case of emergency situations, the evacuation of a large crowd of people is a sophisticated task for fire and rescue services as different strategies must be applied depending on the specific situation. To support the operation of rescue forces, crowd simulation is an established tool for the ex-ante evaluation of strategies. It allows for the objective measurement and comparison of different scenarios. Thus, crowd simulation gains importance for the planning of major events such as festivals or sport events but also for the construction of stadiums, arenas, or travel centers.

Compared to this, the evacuation of public buildings such as town halls, hospitals, and universities is more challenging. These buildings are publicly accessible, they usually do not require physical access control, and the quantity as well as the distribution of visitors, patients, and employees within the building is dynamic as well as unknown. In practice, additional time is required by police, fire, and rescue services to get an overview of these locations. Information regarding the current room utilization must be provided by the management of the institution. Yet, as the quantity and distribution of persons in public buildings is not documented, people in charge at the institution cannot provide the required details such that information for rescue forces is insufficient. The resulting delay of rescue operations can have serious negative effects on the safety and well-being of people staying in the building.

*corresponding author
†http://cirt.uni-trier.de and http://wi1.uni-trier.de

From the perspective of institution's management, the problem is missing information within the decision-making. A lot of data that can be used for gaining a first impression of the current situation is electronically available in different organizational units (e.g., room planning, human resources, or IT department). Yet, it remains unused as it cannot be directly accessed and utilized in this situation. Information is distributed over and stored in different information systems. This heterogeneity of data is as much a challenge as the variability of the interfaces of the systems. With respect to technical gaps or legal contexts, e.g. data privacy, these information systems cannot be accessed centrally.

To overcome this lack of information and to facilitate the planning and execution of rescue operations, this paper aims at identifying, acquiring, and aggregating data sources. Our hypothesis is, that the use of such data enables ad-hoc simulation for decision-support within emergency situation. Therefore, we introduce an innovative approach to estimate the amount of people within public buildings by acquiring and aggregating data from available information systems. We demonstrate the feasibility in context of a case study at Trier University.

The paper is structured as follows: first we present the foundations of crowd simulation and data fusion. Then data acquisition challenges of simulating evacuation scenarios in public buildings are outlined. Finally, a case study illustrates how these challenges can be addressed using the example of Trier University.

BACKGROUND

For the planning of buildings and events as well as for the evaluation of evacuation strategies, crowd simulation is increasingly used, e.g., for evacuation planning of football stadiums (Bateman and Majumdar 2018). Advantages over conventional methods such as investigating flows of individuals using real persons or expert assessments are, among other things, that no people are endangered and that simulations can be repeated as often as required under controlled conditions. This enables the testing of a large number of different scenarios while decreasing costs. Various elements such as global and local route planning, local collision avoidance, behavioral modeling such as integration of personalities, stress or emotions, and movement generation are implemented in crowd simulations (Narain et al. 2009). In many models, the relevance and characteristics of these components differ significantly. Two basic types of models can be distinguished: *Macroscopic* and *Microscopic Models*. Macroscopic approaches consider the crowd as a whole, which offers great computational advantages especially for large crowds. The crowd's behavior is not attributed to specific individuals with their possible and own unique behavior. However, this results in a lack of realism, as individual behavior exists in crowds. Microscopic models, e.g. agent-based social simulation models, aim at precisely reproducing each individual's behavior (Lorig and Timm 2014). Due to increasing computing capacities, these microscopic models are more and more applied and research activities in this field predominate. There is, for example, research on social cohesion (Adam et al. 2019), emotional contagion (Xu et al. 2018), or social capacity of the actor (Valette et al. 2018) in crowd simulations. These factors can influence evacuation behavior, e.g. social cohesion helps to evacuate individuals who would otherwise not be able to evacuate on their own. Another advantage of the increase in computing capacities is that simulation is increasingly used not only to validate security concepts but also as real-time simulation, e.g. Löhner et al. 2018. In this way, simulation can be used as decision support system. Especially in dynamic environments, such as public buildings, this can be useful as not all potential scenarios can be simulated due to their amount. Nevertheless, limitations due to computing capacity may still occur. To this end, so-called *Hybrid Models* are used that combine aspects of both model types such as a parallelization approach to calculate particularly large crowds (Yu et al. 2015). Further details on different models of crowd simulation can be found in the surveys of Pelechano et al. 2008, Zhan et al. 2008, Thalmann and Musse 2013, Ijaz et al. 2015, among others.

Due to the distinctive research in the field of crowd simulation, there is a high quality in behavior generation of actors. However, the models' validity as well as the results' transferability to reality strongly depend on the quality of input data, e.g., the number and the exact position of the persons on site. As a result of insufficient data validity, the operational validity is also low, i.e., the accuracy of the transfer of the results into the problem domain (Sargent 1991). For this reason, there are studies that deal with the use of data from the Global Positioning System (GPS) in real-time simulations (Wirz et al. 2012) and also consider the significance of errors (Zhang et al. 2019). One approach that has been neglected in research in the context of data collection for pedestrian flow simulations so far is the use of several data sources to compensate for missing data and errors. In sensor networks and distributed information systems, data fusion is a common instrument to compensate discrepancies between different sensors and to fill gaps in individual sensors by integrating and aggregating different data sources. The basic principle for this is that intersections exist in the informative value among the individual sensors, which are exploited by many methods and algorithms. For instance, similar approaches use methods such as Bayesian Inference, Dempster-Shafer Inference or Fuzzy Logic (Nakamura et al. 2007). Further methods are presented by Dong and Naumann 2009 as well as in the surveys of Smith and Singh 2006, El Faouzi et al. 2011 and Castanedo 2013. They can also be

transferred from their application context to the given scenario. A similar and widespread approach is the visual evaluation of crowd video material by neural networks to derive behavioral rules of individuals for behavioral prediction in real time (Wei et al. 2018; Bera et al. 2015). These are also data fusion methods, which are not used to increase the validity of the data but to increase model validity.

Summarizing, there is increasing research on crowd simulations but the acquisition of input data is not considered thoroughly even though the simulations' validity depends on input data. Therefore, this paper addresses this research gap by proposing a process for the identification of appropriate heterogeneous data sources as well as fusion of data to simulate crowds in public buildings.

PROCESS OF SIMULATING EVACUATION SCENARIOS IN PUBLIC BUILDINGS

This section proposes a process for simulating evacuation scenarios in public buildings regarding heterogeneous data sources. The process consists of three sub-processes, which shown in Figure 1. It is related to the *JDL Data Fusion Model*, which consists of five levels: *Level 0 - Sub-Object Data Assessment, Level 1 - Object Assessment, Level 2 - Situation Assessment, Level 3 - Impact Assessment, Level 4 - Process Refinement* (Steinberg et al. 2008). In this section, challenges and methods related to identification of data sources, data fusion, and agent-based simulation are outlined in detail.

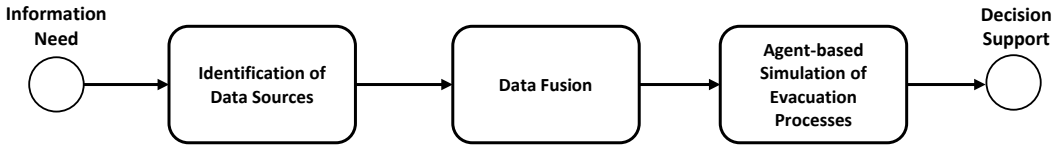


Figure 1. Identified Subprocesses for Using Heterogeneous Data Sources for the Simulation of Evacuation Scenarios

Identification of Data Sources

In a first step, which corresponds to Level 0 of the *JDL Data Fusion Model*, relevant data sources for the subsequent data fusion are identified. This subprocess is necessary because publicly accessible service institutions usually have numerous information systems which either do not provide any information gain or to which direct access is not permitted for legal reasons, e.g., accounting systems. Therefore, the targeted identification and selection of information sources ensure that a sufficient amount of information is recorded.

The process addresses two aspects: First, the emergency services' requirements on information and data quality are identified. Secondly, we outline how the consideration of the structure of the system landscape can positively influence the selection of data sources.

It must be ensured that data sources generate not only data but a **gain in information** which arises when a decision maker, e.g., the police, benefits from the knowledge of this data. However, this presupposes that the user has contextual information and that data is correct as well as not manipulated. In the context of special threat situations, the information requirement of the emergency forces contains two aspects: the evaluation of the threat situation on the one hand, as well as an estimation of when, where, and how many people with which characteristics are present in the area to be evacuated on the other hand (Vreugdenhil et al. 2015). If the number and location of people in the building is known, rescue and evacuation measures can be initiated more quickly and in a more targeted manner.

The second aspect tackles the influence of the **structure of the system landscape** on the selection of data sources. Most of the system landscapes in a building of public services can be characterized by a high degree of network connectivity and interdependencies. The result is that similar or even redundant data is recorded in different systems. For example, if a documentation system depends on the availability of an Internet connection, it could be sufficient and possibly more convenient to monitor Internet access alone, since both systems offer conclusions about the same information gain, i.e., the number of people on site.

However, aggregating more or less redundant data sources can also be advantageous as described in the following subsection. The decision to integrate a system with intersections of information into an already integrated system depends on the information gain generated by the integration of the new system. It is possible to end up with one system that contains a sufficient amount of relevant information but this probably depends on the homogeneity of people and the way they use information systems. In a public building, people are more likely to show heterogeneous usage patterns, suggesting that one data source is not sufficient. It is therefore necessary to aggregate data.

Data Fusion

After identifying relevant and useful data sources, data is usually not yet usable in the application context. Even if data is prepared for technical reasons, e.g., interface preparation, inconsistencies between different data sources can occur and gaps in the database are frequent. Therefore, data fusion aims at the homogenization of data by using several data sources, which probably increases the overall quality of data. This process corresponds to levels 1 to 3 of the *JDL Data Fusion Model*. Data fusion merges the data to avoid inconsistencies and gaps and make the data more accurate and useful. The fact that data from different systems originates from the system landscape of a service of general interest means that it may be available in different formats and that different strategies are pursued to collect measurement data, e.g., cyclic and acyclic measurement. Therefore, we need this process to ensure a basic applicability of the data.

Depending on the information and its source, different forms of information fusion can be classified, which also apply to data fusion: *Complementary, redundant, and cooperative fusion* (Durrant-Whyte 1988). Complementary fusion is characterized by the fact that a composite data image is generated from different information sources. Redundant fusion brings together data sources that basically describe the same information. However, since inconsistencies or gaps may exist in both data sources, the redundant fusion achieves a higher data quality. Cooperative fusion describes the process by which new information is generated by deduction during the merging of information of different data sources. The problem in practice is that the quality of data sources or information is often unknown. Particularly in redundant fusion, it is uncertain which data sources has a higher quality as well as information content and should therefore dominate during calculating the data. In the application context of threat situations in public buildings, it can be assumed that the information systems chosen as information sources diverge to a certain extent from actual reality. The uncertainty is therefore even greater than in a classical Wireless Sensor Network (WSN). For this reason, an empirical study is essential to value the quality of data and it is necessary to differentiate between types of data, the measurement method of the data, and the temporal as well as spatial dimension. This results in three classes of problems which have to be considered in the given application context:

1. the discrepancy between the measurement and planning data of the information systems and the real situation,
2. the discrepancy between the measurement time of the information system and the specific simulation time, as well as
3. the estimation of an exact geo-localization of individuals in the building.

The first problem is, that a certain discrepancy can be assumed between the measurement and planning data of the information systems and the real situation (1). For instance, during the work process in an administrative office for citizens, the system which measures the number of employees logged on to an information system may differ from the real number of people on site, as not all employees necessarily have to use this system for their work or several employees have different logins to this system. Furthermore, visitors can be counted in this public office by measuring the visit dates in the calendars of the employees. However, the number of visitors on site can deviate from this as on the one hand visitors may skip an appointment and on the other hand they may appear without an appointment. Simultaneously, there is an uncertainty whether the information of different data sources is complementary or redundant. Possible double counts can create a discrepancy between measurements and reality.

The second challenge is that there may be a discrepancy between the measurement time of the information system and the specific simulation time (2). This challenge can be divided into three aspects: First of all, with period-related data, a conclusion must be drawn about the time of simulation. For example, visitors to the administrative office for citizens can be late for an appointment. Secondly, in rare cases, measurements are collected continuously. Mainly, these are discrete measurements that are carried out in a certain time interval. In the above example of the registrations of the employees of the public office at an information system, if the data are collected in a cycle of 15 minutes, an interpolation must be carried out to determine the data of a simulation time, which lays between the collection of times. Finally, a measured time or information at a time (planning data) can have an effect on pre- or post-states. If a visitor of the public office has an appointment with an employee, he or she may be in the building long before the appointment, e.g., to be on time, or still be in the building after the appointment, e.g., to complete documents.

The third class of problems is that with many systems, especially in combination with the second category, an exact geo-localization cannot be carried out (3). If an employee of the administrative office logs in at a wifi access point, this person can be in the entire transmission area of the access point. During appointments, employees and visitors can be located anywhere in the specified room. This may be irrelevant for small rooms with a few people present but in large rooms with a large number of people present this can seriously effect an evacuation event. However,

observations and other knowledge can be used, e.g., queues or explicit waiting and sitting areas where people are more likely to stay.

We believe that all three problem classes can be addressed by methods of data fusion. Established methods like heuristics and Machine Learning mentioned in Section 2 will be used to remove gaps and inconsistencies. However, both aspects require a reliable evidence about real data, which is why an empirical data collection is essential to determine the error probabilities and to adapt the measured data to the real data. The overall aim of the data fusion's synergistic multiple use of different information sources is to produce more accurate and consistent data than could be produced by any single data source alone. This has to base on the measurement and planning data.

Agent-based Simulation of Evacuation Processes

Once data has been aggregated and adapted to the state of reality, an agent-based simulation of an evacuation process can be carried out, which corresponds to level 4 of the *JDL Data Fusion Model*. This sub-process is recommended because it allows us to react objectively to the numerous possible scenarios that can occur in buildings with high dynamics. It assumes that a model of the public building to be investigated exists in crowd simulation software. Usually respective simulators allow for the execution of a number of simulation experiments with systematic parameter combinations. By varying a large number of parameters, the best evacuation strategy can be determined without performing experiments within the real system.

Summarizing, the process of simulating evacuation scenarios in public building regarding heterogeneous data sources consist of three sub-processes: During identification of data sources, it must be ensured that there is a gain in information by integrating systems, whereby the structure of the system landscape can be regarded. In the sub-process of data fusion there are three main problem classes which have to be handled to generate consistent and accurate data. By using this data, the the validity of the crowd simulation can be increased. The applicability of the proposed methodology is demonstrated in the following case study.

CASE STUDY

On 24th November 2017, a student of Trier University threatened to use armed violence on the campus. Although police was able to identify and arrest the student at an early stage, they carried out an extensive intervention at the university and cordoned off the campus. At that time it was not certain whether possible accomplices existed or whether hazardous material or weapons were already on the campus. The campus of Trier University is characterized by its wide accessibility, since there are entrances in all directions. This implies that situation assessments take a great amount of time and that decision makers in special situations can only plan and carry out a necessary evacuation after a delay. Ultimately, the specific threat was not confirmed at Trier University but the incident has revealed exactly such delays. Therefore, there is still a lot of potential in the aggregation of information, especially since the information was actually available in various systems. The following case study is carried out using the example of Trier University respecting the specific described challenges. Its purpose is to show the applicability of our process using heterogeneous data sources for the simulation of evacuation scenarios in public buildings. Our study is initially limited to one building, which, however, has a particularly high dynamic in the number of persons on site. It contains the largest lecture hall of the university, the Auditorium Maximum, with over 500 seats, and the main canteen on campus (see Figure 2). The building has entrances and exits in all directions and the canteen consists of three open floors.

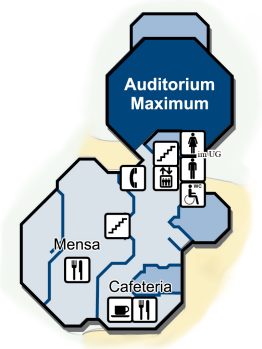


Figure 2. Site plan Auditorium Maximum and canteen (Floor 1)

Data Sources

In a first step, relevant data sources are identified to satisfy the need for information regarding the location of persons at specific points in time. We identify three useful data sources: the integrated campus management system of Trier University (**PORTA**), the **wifi access points**, and the **canteen cash system**.

PORTA provides information on events at the university's facilities. Each room has a capacity of seats and a list of events, e.g. lectures, taking place in the room. Participant lists exist for the events, since online registration is mandatory for participants to take part in a lecture or event. By using the PORTA system, conclusions can be drawn about the future planned occupancy of the Auditorium Maximum. Deviations from this plan can occur, for example, due to the short-term cancellation of an event or the absence of registered attendees.

Another source of information is the number of registered devices that are connected to a **wifi access point**. This is logged by the university's IT department. Each student and employee receives an ID which they can use to access the university-wide wifi. The SSID of all access points is identical, which guarantees a login at the best transmitting access point (probably the closest one). There are currently four access points in the selected building: two in the Auditorium Maximum (AP03 + AP04), one in the foyer area of the building (AP02), and one in the canteen (AP01). A further access point in the Mensa will be installed soon. Figure 3 shows an example of a day with wifi use in the corresponding building. The increasing number of registered devices at the access point at lunchtime (middle of the diagram) is obvious. It is characteristic of the two access points in the Audimax that the number of registered devices is relatively stable over the period of the lectures. The rapid rises and falls in the number of registered devices correspond to the times when the lectures begin and end. Between these events there are peaks of the access point in the foyer area, where most students enter and leave the building for visiting lectures.

Since the canteen also sells food to people who do not belong to the university, there may also be people on site who have not yet been registered by the two sources of information mentioned above. For this reason, the **canteen cash system**, which logs every meal sold, is also a relevant source of information to be used in the case study. A customer group, e.g. students or guests, is logged for each purchased meal, which is helpful for the subsequent data fusion process.

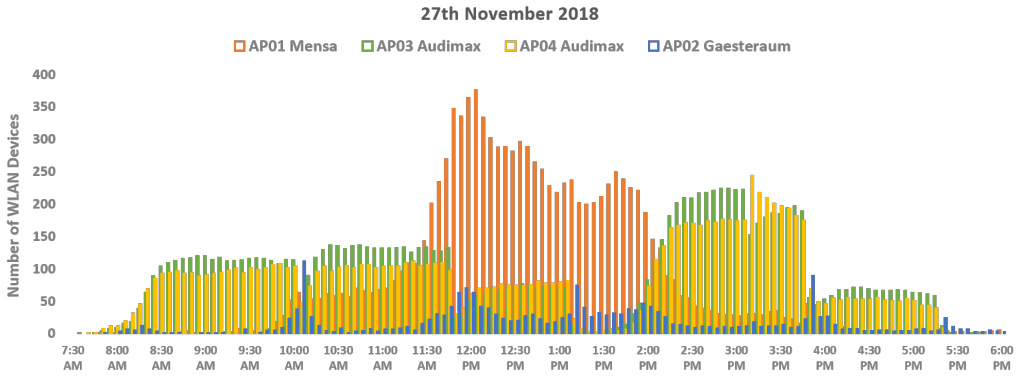


Figure 3. Number of devices logged at wifi access points

Data Fusion

Classical applications of the data fusion process can often determine the actual form of the information. Redundant fusion generates a sufficiently accurate measure that is often sufficient in practice. The given application case differs from these classical redundant fusion systems in that highly heterogeneous data sources are available and the problem classes described above occur simultaneously (cf. Sec. 3.2):

The first problem is that there may be a certain discrepancy between the measured as well as the planning data and reality (1). For example, if a system measures the number of registered devices at a wifi access point, this does not necessarily correspond to the actual number of people in the area of the access point. On the one hand, there may be people who are not logged in with a wifi-enabled device. On the other hand, persons may own more than one mobile device with which they are logged in. Furthermore, in the case of a system that documents student registrations for courses the number of students on site may differ significantly from the number of registered students. The question arises what is the real situation, since the examples show that both systematic overfitting and systematic underfitting are possible. Simultaneously, it is difficult to determine whether data is more redundant or complementary. For instance, double counts by logon to wifi and purchase of a meal are possible. Due to the

heterogeneity of the data and the lack of knowledge of the probability of errors in the data, it is not possible to approximate the most probable real state. For this reason, empirical surveys were carried out at various times during the semester in which the number of persons on site and the number of wifi devices used per person were counted. This data serves as fixed points (training data) to implement a valid approximation, e.g. by using neural networks to predict the real situation. Currently, we cannot assess the success of overcoming this problem. Nevertheless, both redundancy and complementarity allow us to limit the possible variable space by a lower bound (full redundancy) and an upper bound (full complementarity), which should be very helpful in the subsequent simulation experiments.

The second challenge is that there may be a discrepancy between the measurement time and the specific simulation time (2). As explained in Section 3, this challenge has three aspects, which are explained below: First, the PORTA data source is a period-related data source. Conclusion about a specific point in time can be subject to certain patterns. For example, it is possible that students regularly arrive too late for an event. These patterns can be detected using wifi data. Furthermore, the wifi data source represents an information source at a time measured in a cycle of 5 minutes. If the time to be simulated is not exactly such a measurement time, an approximation must be made, which can be done by interpolating the two adjacent measurement times. Finally, the information source of the food sold in the canteen has a time reference which, however, has a high impact on subsequent states. Thus, it can be assumed that a person who buys a meal in the canteen is highly likely to remain in the canteen for a specific period of time. The wifi data again helps to draw a conclusion from the time a meal was bought to the length of stay in the canteen.

The third problem is how to deduce the exact geolocation from the data collected (3). When logging on to the wifi, the person with the mobile device can be in the entire coverage area of the network. In room reservation plans, the registered number of persons can also be in the entire room. This problem is particularly serious because small deviations from reality can have fatal consequences in the evacuation process. We meet this challenge by dividing the area inside the building into zones. Using the wifi data, the PORTA data and an empirical survey of agglomerations, we suggest that specific zones are likely to be occupied.

At the end of the data fusion process, the fused and approximated data is provided in an SQL database to be accessible to decision makers from multiple systems, such as a dashboard. The completely fused data as well as the adjusted data of different data sources can be retrieved in separate tables. This ensures flexibility in the use of the data. Figure 4 summarizes the data fusion process of the three chosen data sources considering their specific interdependencies.

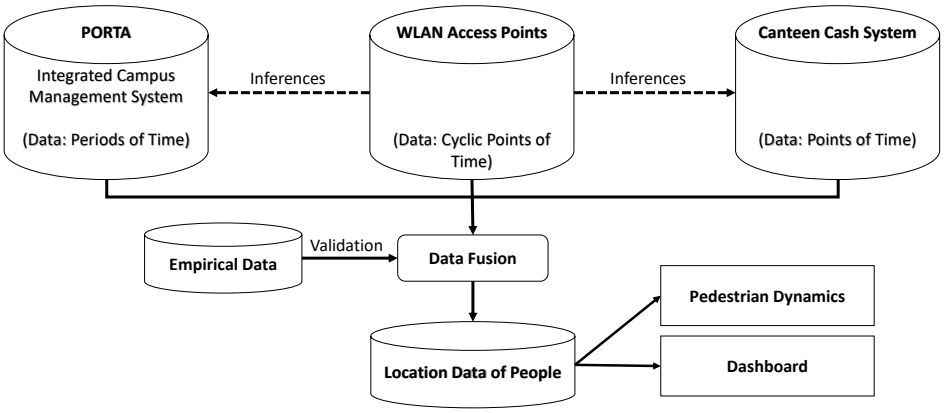


Figure 4. Used data sources for generating inferences

Evacuation Processes at Trier University

Even if a dashboard should be very useful for decision makers in threat situations to get aware of the current situation, the main goal of data fusion of heterogeneous data sources at Trier University is conducting evacuation simulation studies with focus on the flow of involved persons. The model of the relevant parts of the campus was implemented using the *Pedestrian Dynamics* simulator by *INCONTROL*. Figure 5 shows parts of the models. The challenge so far has been where valid data comes from as simulation input. We are addressing this challenge by processing the data in the data fusion process. In this way, we can achieve situation-dependent decision support concerning evacuation strategies.

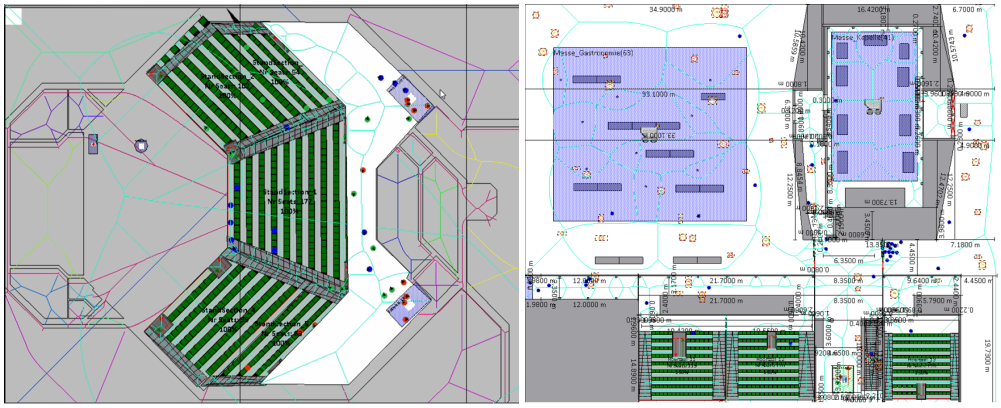


Figure 5. Pedestrian Dynamics models of Auditorium Maximum (left) and lecture halls (right) at Trier University

CONCLUSION AND FUTURE WORK

A lot of data required for gaining a first impression of the current situation in special threat situations is electronically available in different information system but remains unconsidered as it cannot be directly accessed and utilized. This paper proposes a process of the identification of appropriate heterogeneous data sources as well as the aggregation of data by means of data fusion. This process aims at supporting decision-making in emergency situations by using ad-hoc simulation of evacuation strategies. As a key aspect, we focus on increasing the quality of parametrization as well as the level of validity.

To evaluate this process a case study at Trier University is carried out. We identified and selected relevant data sources. Additionally, we built a simulation model of the campus in the software *Pedestrian Dynamics* for investigating evacuation scenarios. Currently, the necessary interfaces are being implemented to integrate the distributed available data into our workflow. In future work, we will elaborate on specific algorithmic approaches for the estimation of amount and distribution of individuals within public buildings. We will draw samples by manual people counting in our case study. Additionally, the agent representation should be extended by emotional and cognitive behavior such that realistic crowd behavior emerges.

ACKNOWLEDGMENTS

The authors would like to thank the research assistants Kira Huneke and Fabian Mirz for their substantial contribution to this research. Furthermore, the authors are thankful to the Studierendenwerk Trier (canteen) and the University's IT department (ZIMK) for providing data and information as well as to the administration of Trier University for financial support to this study.

REFERENCES

Adam, C., Garbay, C., and Dugdale, J. (2019). "Multi-factor model and simulation of social cohesion and its effect on evacuation". In: *Proceedings of the 52nd Hawaii International Conference on System Sciences 2019*. ICT and Artificial Intelligence for Crisis and Emergency Management.

Bateman, G. and Majumdar, A. (2018). "An Assessment of the Simulation Modeling of Emergency Evacuation in Sports Stadiums". In: *97th Transportation Research Board Annual Meeting*.

Bera, A., Kim, S., and Manocha, D. (2015). "Efficient trajectory extraction and parameter learning for data-driven crowd simulation". In: *Proceedings of the 41st Graphics Interface Conference*, pp. 65–72.

Castanedo, F. (2013). "A review of data fusion techniques". In: *The Scientific World Journal* 2013, pp. 1–19.

Dong, X. L. and Naumann, F. (2009). "Data fusion: resolving data conflicts for integration". In: *Proceedings of the VLDB Endowment* 2.2, pp. 1654–1655.

Durrant-Whyte, H. F. (1988). "Sensor models and multisensor integration". In: *The international journal of robotics research* 7.6, pp. 97–113.

El Faouzi, N.-E., Leung, H., and Kurian, A. (2011). "Data fusion in intelligent transportation systems: Progress and challenges – A survey". In: *Information Fusion* 12.1, pp. 4–10.

Ijaz, K., Sohail, S., and Hashish, S. (2015). "A survey of latest approaches for crowd simulation and modeling using hybrid techniques". In: *17th UKSIMAMSS International Conference on Modelling and Simulation*, pp. 111–116.

Löhner, R., Haug, E., Zinggerling, C., and Oñate, E. (2018). "Real-time micro-modelling of city evacuations". In: *Computational Particle Mechanics* 5.1, pp. 71–86.

Lorig, F. and Timm, I. (2014). "How to model the "human factor" for agent-based simulation in social media analysis?" In: *Simulation Series* 46, pp. 89–94.

Nakamura, E. F., Loureiro, A. A. F., and Frery, A. C. (2007). "Information fusion for wireless sensor networks: Methods, models, and classifications". In: *ACM Computing Surveys (CSUR)* 39.3, pp. 1–55.

Narain, R., Golas, A., Curtis, S., and Lin, M. C. (2009). "Aggregate dynamics for dense crowd simulation". In: 28.5, pp. 1–8.

Pelechano, N., Allbeck, J. M., and Badler, N. I. (2008). *Virtual crowds: Methods, simulation, and control*. Vol. 8. Synthesis lectures on computer graphics and animation. Virginia: Mongan & Claypool.

Sargent, R. G. (1991). "Simulation model verification and validation". In: *Proceedings of the 23rd conference on Winter simulation*. Ed. by B. L. Nelson, W. D. Kelton, and G. M. Clark, pp. 37–47.

Smith, D. and Singh, S. (2006). "Approaches to multisensor data fusion in target tracking: A survey". In: *IEEE transactions on knowledge and data engineering* 18.12, pp. 1696–1710.

Steinberg, A. N., Bowman, C. L., and White, F. E. (2008). "Revisions to the JDL data fusion model". In: *Handbook of multisensor data fusion*. CRC Press, pp. 65–88.

Thalmann, D. and Musse, S. R. (2013). *Crowd Simulation*. 2nd ed. 2013. London: Springer.

Valette, M., Gaudou, B., Longin, D., and Taillandier, P. (2018). "Modeling a Real-Case Situation of Egress Using BDI Agents with Emotions and Social Skills". In: *PRIMA 2018: Principles and Practice of Multi-Agent Systems*. Ed. by T. Miller, N. Oren, Y. Sakurai, I. Noda, B. T. R. Savarimuthu, and T. Cao Son. Cham: Springer International Publishing, pp. 3–18.

Vreugdenhil, B. J., Bellomo, N., and Townsend, P. S. (2015). "Using Crowd Modelling in Evacuation Decision Making". In: *International Systems for Crisis Response and Management (ISCRAM)*.

Wei, X., Lu, W., Zhu, L., and Xing, W. (2018). "Learning motion rules from real data: Neural network for crowd simulation". In: *Neurocomputing* 310, pp. 125–134.

Wirz, M., Franke, T., Roggen, D., Mitleton-Kelly, E., Lukowicz, P., and Tröster, G. (2012). "Inferring crowd conditions from pedestrians' location traces for real-time crowd monitoring during city-scale mass gatherings". In: *IEEE 21st International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises*. IEEE, pp. 367–372.

Xu, M., Xie, X., Lv, P., Niu, J., Wang, H., Li, C., Zhu, R., Deng, Z., and Zhou, B. (2018). "Crowd Behavior Simulation with Emotional Contagion in Unexpected Multi-hazard Situations". In: *Computing Research Repository (CoRR)*.

Yu, T., Dou, M., and Zhu, M. (2015). "A data parallel approach to modelling and simulation of large crowd". In: *Cluster Computing* 18.3, pp. 1307–1316.

Zhan, B., Monekosso, D. N., Remagnino, P., Velastin, S. A., and Xu, L.-Q. (2008). "Crowd analysis: a survey". In: *Machine Vision and Applications* 19.5-6, pp. 345–357.

Zhang, L., Lai, D., and Miranskyy, A. V. (2019). "The impact of position errors on crowd simulation". In: *Simulation Modelling Practice and Theory* 90, pp. 45–63.

Communication in Emergency Management through Data Integration and Trust: an introduction to the CEM-DIT system

Fiona McNeill*
Heriot-Watt University, Scotland
f.mcneill@hw.ac.uk

Diana Bental
Heriot-Watt University, Scotland
d.s.bental@hw.ac.uk

Paolo Missier
Newcastle University
paolo.missier@ncl.ac.uk

Janetta Steyn
Newcastle University
janetta.steyn@ncl.ac.uk

Tom Komar
Newcastle University
tom.komar@ncl.ac.uk

Jeremy Bryans
Coventry University
jeremy.bryans@coventry.ac.uk

v1.1.1
2018/09/10

ABSTRACT

This paper discusses the development of the CEM-DIT (Communication in Emergency Management through Data Integration and Trust) system, which allows decision makers in crises to send out automated data requests to multiple heterogeneous and potentially unknown sources and interactively determine how reliable, relevant and trustworthy the responses are. We describe the underlying technology, which is based partially on data integration and matching, and partly on utilisation of provenance data. We describe our cooperation with the Urban Observatory (UO), which allows us to develop the system in collaboration with developers of the kind of crisis-relevant data which the system is designed for. The system is currently in development, and we describe which parts are fully implemented and which are currently being developed.

Keywords

Provenance, Data matching, Data integration, Semantic web systems, Decision support

INTRODUCTION

It is well understood that responses to crises are often hampered by the inability to share data quickly and efficiently. Living in a world of data means not only that huge data sources are available but also that huge numbers of different data sources exist, many of which may contain data that is relevant to any given situation. But these data sources are generally heterogeneous, may be hard to understand and derive from a wide variety of sources, some of which may be unknown and/or untrusted. The traditional approach to data exchange during crisis management - largely through direct human interaction - is simply unable to access and process these data sources in depth, which can mean that important and relevant pieces of information are unavailable to decision makers at the crucial time. In order to make full use of all this data, automated and interactive intelligent systems are required to discover, filter, interpret and annotate potentially relevant data for efficient and effective consumption by decision makers. The fact that such

*corresponding author

systems are not in place is a reflection of the difficulty of designing them. There are several technical difficulties around this problem; two pressing ones that require intelligent solutions are *(i)* How to deal with data heterogeneity? When data in different resources will use different terminology, different structure, different formats and so on, how can this data be made mutually comprehensible and how can decision makers understand how data from some source is relevant to what they want to know when it might appear very different? Secondly *(ii)* when data is derived from multiple sources, some of which are unknown, how can decision makers trust that data? How can they find out what they need to know about where the data comes from in order to be confident in making decisions based on it? It is crucial for decision makers that the data they receive is believable, can be trusted and is of an acceptable quality (Prat and Madnick 2008). Provenance provides transparency into the sources and processing history of the data (Alper et al. 2016).

In this paper, we describe the CEM-DIT system, which will allow decision makers to send out automated queries to multiple data sources, and interactively explore potential responses to their queries in order to determine whether or not the responses meet their requirements. The system is based on extensive work by the authors in data integration and in provenance, and focuses on integrating these two orthogonal issues into a unified system that priorities the autonomy of the decision makers to explore options and explanations and thereby to make decisions with confidence.

The theoretical underpinning of the system is well developed and the system already exists in part. However, full integration and design decisions remain to be done, and we present this work in progress to the ISCRAM community in the hope of getting feedback and interaction that will be helpful in guiding this process.

In the paper, we first outline the related work to show how our approach extends the state of the art. Next we describe the CEM-DIT system, and then describe the underlying technology in a little more detail. We describe our data-driven development and evaluation, and finally outline our next steps and conclude the paper.

RELATED WORK

In this section, we describe how the overall approach compares to other attempts to address the problem, and then explain how the underlying technology is particularly suitable for this task, and to describe the concept on which the system is based.

Data-driven decision making support

During crises, communication must be created and maintained between different organisations, as well as between organisations and the public. A considerable amount of humanitarian data is widely available, including open data, which can be of value to decision makers. However the data formats vary massively and single problem context requires identifying and extracting the relevant and meaningful parts from many systems for representation (Paulus et al. 2018)

Much current research focusses on communication between crisis management organisations and the public, on creating channels for communicating necessary information to the public and using information from crowdsourcing and social media to contribute to the success of emergency management (Freitas et al. 2016), (Ruiz-Zafra et al. 2014). Trust and provenance are significant issues in using such data. Interoperabilty is also recognised as a problem in communication between organisations (Fischer et al. 2016). There is a lack of suitably structured information (Rietjens et al. 2009), and when structured information exists the terminology, formats and structures vary between organisations. While there is work at an organisational level on creating co-operation between agencies, our work focuses on data interoperability between agencies at a semantic level, and on dynamic use of disparate data so that data sources not previously identified and integrated before runtime can be utilised.

Query Rewriting and Provenance

The CEM-DIT system is based on dynamic structural semantic query rewriting, as well as user-focussed provenance encapsulation and exploration. To the best of our knowledge there are no other approaches using failure-driven reasoning techniques combined with matching techniques to dynamically rewrite queries. Work by (Quesada Real et al. 2017) and (Shamoug et al. 2018) addresses the differences in the ways language is used in different organisations which make information sharing more complex. Ontologies offer an approach to linking the different terminologies within organisations and to represent explicitly both differences and similarities in the way that terms are used and understood (Galton and Worboys 2011; Burel et al. 2017). Ontologies have been used to support decision makers in crisis management in different organisations. (Burel et al. 2017) derives an ontological model to represent crises and demonstrates its use to support document sharing for crisis management. RESCUER (Simas et al. 2017) provides semantic interoperability in crisis management by applying ontology-based schema matching to integrate

crowdsourced data with more detailed data from pre-existing systems in command and control. Our approach is similar to that of RESCUER, but differs in that we use structured semantic matching in addition to ontology matching, which allows us to match not only the terminology but the structure of a query, and we apply them to query response rather than data integration.

Data provenance is a structured form of metadata designed to records the activities and datasets involved in data production, as well as their dependency relationships. The PROV data model (Moreau et al. 2013), released by the W3C in 2013, defines a schema and constraints that together provide a structural and semantic foundation for provenance. This enables the interoperable exchange of provenance between data producers and consumers. In addition to containing references to data generation or transformation processes, a *provenance trace* typically includes input or intermediate data products as well as references to *agents*, that is the humans or software systems who were responsible for enacting those processes. In multi-party collaboration settings that involve data sharing, as well as in third party auditing of data and processes, there is a broad expectation that shipping the available provenance to collaborators, or more generally publishing it along with the data, may help data consumers, including auditors, form judgments regarding the reliability of the data itself.

There is however a tension between the potential for using provenance to establish data reliability, and its complexity. Provenance-aware information systems are equipped with provenance-capture capabilities, which in many cases allow fine-grained, detailed provenance traces to be collected automatically by the underlying system, cf. (Gehani and Tariq 2011). Provenance that is collected about high-level processes such as workflows is less detailed, but still not suitable to be understood by humans, especially decision makers on the receiving end of query results, who are not familiar with the systems that generated the data in the first place. For the same reason, it is not reasonable to assume that the same decision makers will be able to query the provenance in order to extract its expected value. it is therefore necessary to simplify the provenance content in order to make it understandable by these users. At Newcastle we have addressed this problem in the context of selective disclosure of provenance, i.e., when provenance that is exchanged between parties with limited mutual trust needs to be partially *obfuscated* (Missier et al. 2014). In this work we adopt a similar approach and reuse some of the same ideas, namely to create views over the raw provenance trace, this time with the aim to support interactive exploration of complex provenance graphs by decision makers.

The CEM-DIT system not only utilising this matching and provenance technology, but in addition the integration of these technologies is unique. This allows us to create a system where a decision maker can not only access heterogeneous data from multiple disparate data sources, but can be provided with the tools to appropriate evaluate the data, and hence make well-justified decisions, addressing two crucial and orthogonal issues in data sharing.

AN INTEGRATED SYSTEM FOR DECISION MAKERS

In this section, we outline what the CEM-DIT system will ultimately look like, highlighting what is already in place and what remains to be done.

We illustrate CEM-DIT through a scenario in which there has been a major unexpected flood in the city centre. Emergency services want to enter the central area by the fastest route, while people and traffic are leaving by many routes. The emergency services need to know who is still in the area and to plan routes which are open and not obstructed by the flood or by people leaving. Traffic levels in some parts of the central area are routinely monitored by local traffic police using CCTV and electromechanical sensors. In addition, a new service is available which monitors traffic in some locations using satellite imagery. However this service is under development and is not fully integrated. These different sources of traffic data are offered in different locations by services using different formats and interfaces. The CCTV and satellite image data are automatically interpreted using image analysis software and complex machine learning algorithms. Data from different sources is not always available and new algorithms may not produce fully reliable data. The CEM-DIT system gathers, processes and returns potentially relevant data to the decision maker, together with the metadata necessary for the decision maker to make an informed decision. Figure 1 illustrates the workflow this involves.

STEP 1: Data is requested

The decision makers send out an automated query[1], written in a formal querying language. The query can either be sent out to a list of known data providers, or can be broadcast to anyone interested in responding.

In our running example, we consider a query in which the decision maker needs to know the traffic levels which have been recorded by each of the sensors in an area at a given time, with their identifiers and locations.

[1]This can be pre-written prior to interaction for predictable queries. For non-predictable queries, we are investigating systems that automatically generate formal queries from natural language text. In the meantime, non-predictable queries will require the presence of someone (the decision maker or someone else) who is able to create queries.

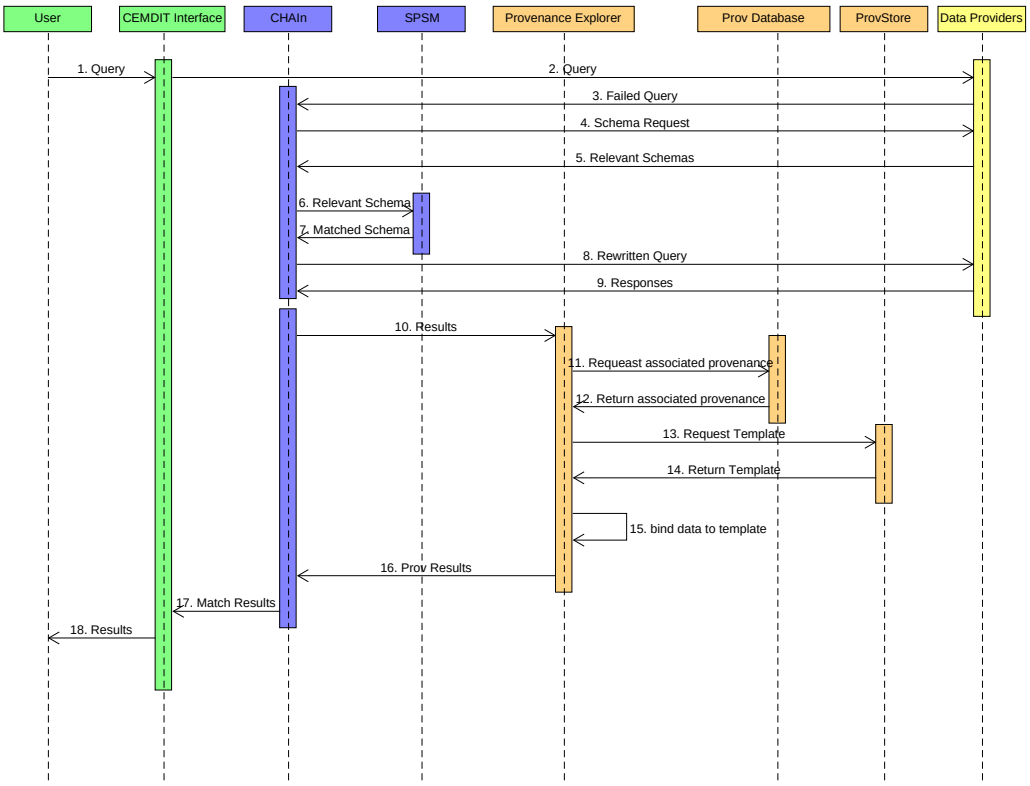


Figure 1. Sequence diagram showing the flow of data in the CEM-DIT system

STEP 2: CEM-DIT retrieves and sorts relevant data

- Multiple data sources receive the query. The query will be written according to a certain schema and will use certain terminology . Unless extensive pre-alignment has taken place, it is unlikely that the receiving data source will use precisely the same schema and/or terminology, and therefore the query will fail, even if there is data in the data source that is relevant. This is illustrated by the example query which initially involves six arguments in a given order, and talks about *latitude*, whereas relevant data sources may use the term *sensor centroid latitude* for a similar or identical concept, and may have additional or missing attributes. At this point, the CHAIn (Combining Heterogeneous Agencies' Information) matching system (McNeill et al. 2014) is initiated. It filters the data source for anything potentially relevant, and then perform detailed structural-semantic matching on potential candidates. This matching provides a map of how to rewrite the query in such a way that it is similar to the original query but capable of returning data from the data source. The process determines: 1) how similar, indicated by a score $S \in [0..1]$, the rewritten query is to the original query; b) what assumptions, rewritings and removals have been used to create the rewritten query. Any rewriting with a score S that passes a given threshold S_t is sent to the data source and the results returned to the CEM-DIT system.

- When the data is returned in response to the rewritten queries, it is annotated with any provenance data associated with it. This may be simple metadata such as the data source it came from and when it was generated, but may be much more complex - for example, complete pipelines which include applications and parameters that were used to produce the data. ProvExplorer is the part of the CEM-DIT system that extracts and visualises provenance.

  ProvExplorer requests access to the database that associates a query with locations where provenance is stored. The database also contains the ID of a provenance template which is stored in ProvStore[2].

STEP 3: Data is presented to the decision maker and evaluated

[2]ProvStore is a web service for storage of provenance documents (`https://openProvenance.org/store`)

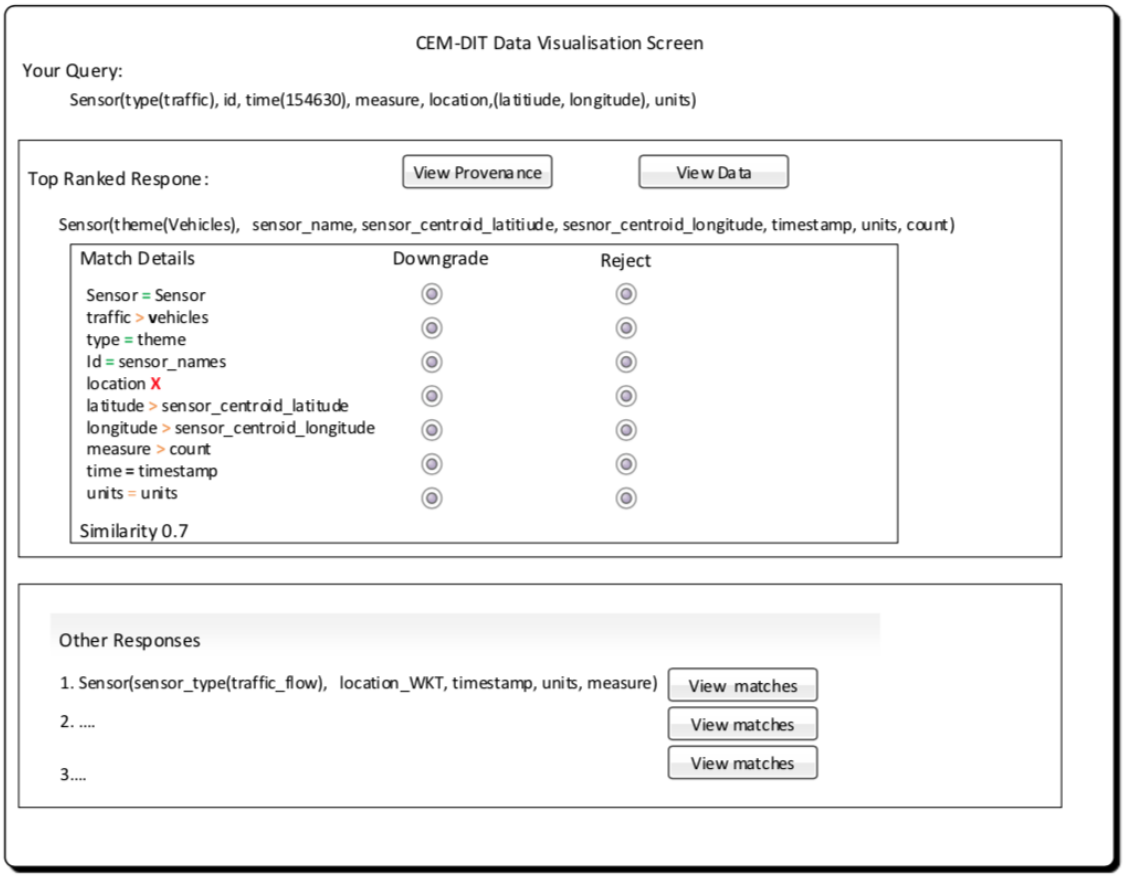


Figure 2. Mock up of a response screen for a query

The annotated responses are presented to the decision makers through the CEM-DIT system in a way that allows a decision maker to visually explore the potential responses. This step is currently under development. Here, we outline what the system is going to look like.

The CEM-DIT system presents the different options for query rewriting (if more than one passed the threshold) to the decision maker, clearly indicating where substitutions, approximations and non-matches have been made. Figure 2 shows a mock-up of the screen the decision maker would see after sending out the example query asking for data from sensors that are monitoring traffic at a given time stamp 154630. Although the query will have been sent to the data source in SQL or a similar querying language, it is presented to the decision maker as a first-order term, stripping out the querying language syntax, as this is easier for the decision maker to understand. The example query described in Step 1 will be rendered as follows:

sensor(type(traffic), id, time(154630), measure, location(latitude,longitude), units).

The schema of the top ranked response is shown, and a list of the matching of every aspect of the original query is given. The structural and semantic similarity between the top-scoring query and data source is reflected in the relatively high match similarity at 0.7. The score is lowered by differences in terminology and structure. For example, *traffic* and *measure* are more general terms than *vehicles* and *count*; a nested structure for *location* in the query is missing from the data source although its components (*latitude* and *longitude*) are both identified. Any components that are present in the data source but are not used in the query do not affect the match score. The decision maker can choose to downgrade or reject any of these matches, and if this is done it will cause all matches to be reranked, with all containing the unacceptable match either downgraded or removed from the list (depending on the type of downgrading chosen). Downgrading a match means penalising a particular aspect of it more heavily. For example, in the match details in Figure 2, we can see that a match *ID = sensor_names* is considered to be equivalent by the matching system, which means the match from the one to the other does not cost anything (i.e., reduce the overall similarity score), but the decision maker may consider that in this context they are related but not identical - hence choosing the 'downgrading' option - or that they are not related - hence choosing the 'reject' option. The former choice will add a cost to removing the match, and the latter will rule it out as a possibility, leading to a different (reduced) matching score. If this match also occurs in other schema matches, then similar alterations to the

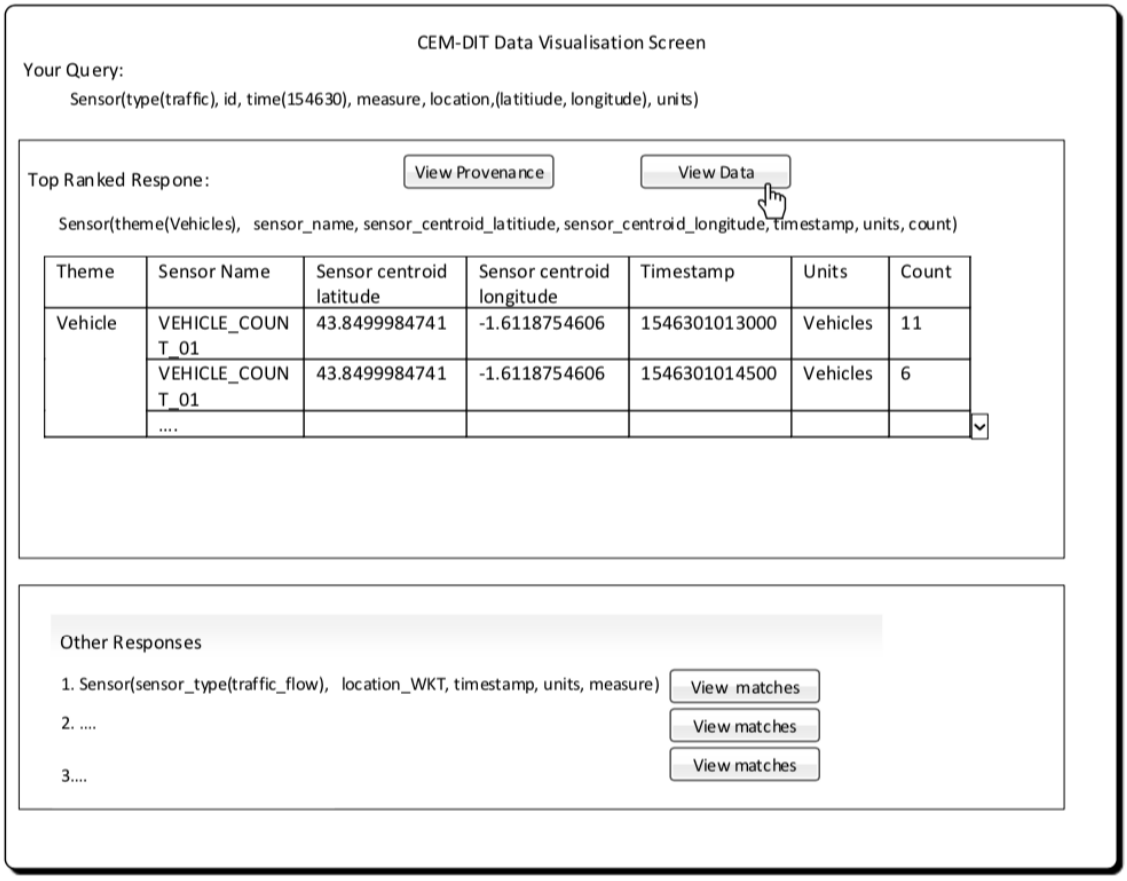


Figure 3. Mock up of data associated with the top-ranked response

cost will also occur in those matches, potentially leading to a reranking of the returned results. The decision maker can see the data associated with the top-ranked response by clicking on the *view data* button, as illustrated in Figure 3. The decision maker can also choose to view more detail about other matches lower down the ranking.

The decision maker can choose to view and explore the provenance associated with each aspect of the top schema. Initially a simplified provenance graph is presented, as illustrated in Figure 4. We can see some of the provenance of *count*, which is based on a model and an image. In order to feel confident of the data, the decision maker may then choose nodes in the provenance graph to explore further, to get more insight into how *count* is generated. Figure 5 illustrates the graph the decision maker would see if she expanded both *model* and *count* (this is shown outwith the CEM-DIT screen to improve readability). Any node highlighted in red can be expanded to expose more provenance data; for nodes that are not highlighted there is no more additional provenance data available. This additional provenance may be lacking either because data owners have not have recorded or stored full provenance for the data, or because they are unwilling to share all aspects of provenance for commercial or privacy reasons. If provenance data that the decision maker wants to see is not available, she can downgrade the match on that basis. As with the matching downgrades, in the finished system this information will be propagated to other matches, and any that do not contain essential provenance information will be removed.

Once the decision maker is confident that a particular result is acceptable from both a matching and a provenance point of view, she is able to accept it and the data attached to that result can be used, either automatically, interactively or by hand, in any decisions to be made.

This step is partially implemented. The key steps that are still to be implemented are outlined in the Next Steps section.

UNDERLYING TECHNOLOGIES

The core functionality of the CEM-DIT system depends on our work on provenance and on query repair. Here, we briefly explain these technologies.

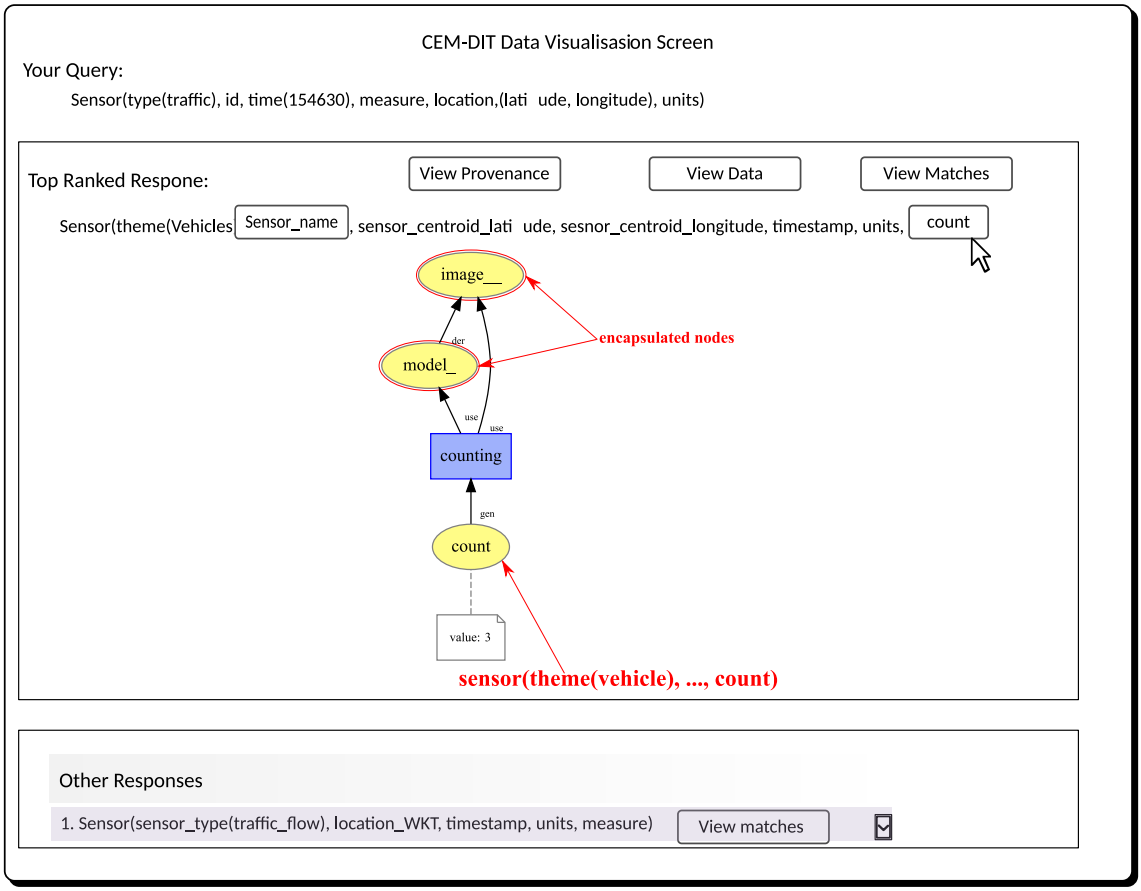


Figure 4. A simplified provenance model which is shown to the decision maker in the first instance. The original query is shown in red with an arrow pointing to the result for count.

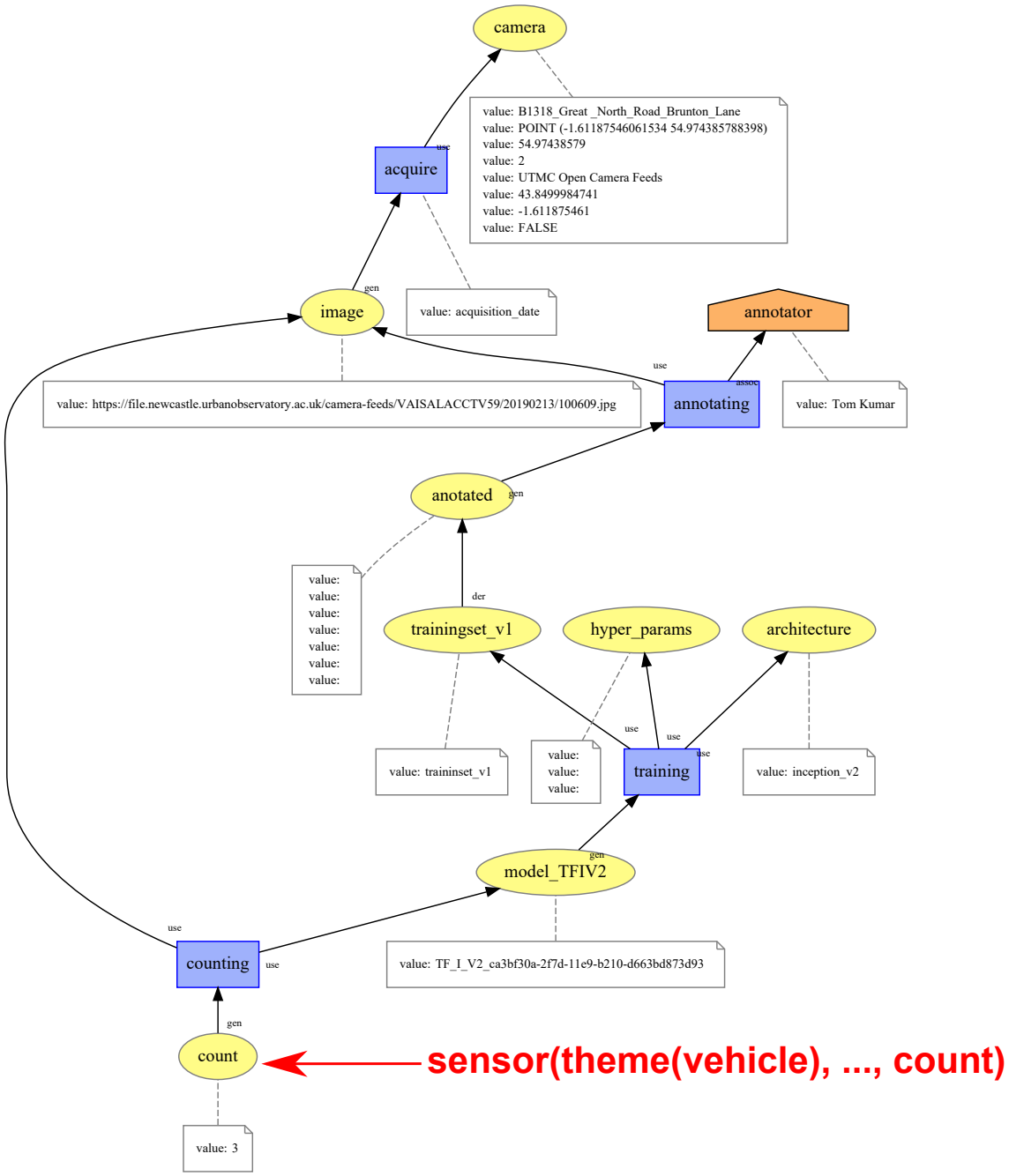


Figure 5. The provenance graph of all provenance retrieved for the results. Where 'value:' is shown, in the attributes, with no value, the provenance was not available.

ProvExplorer

Provenance can be provided as meta-data when queries are made. When provenance is not available directly with the data it may also be obtained from a separate provenance store which is maintained by the data provider or a third party such as ProvStore. By mapping the retrieved provenance to entities, activities and agents, according to the W3C provenance standards (https://www.w3.org/standards/techs/provenance#w3c_all), we are able to visualise it as a provenance graph. Such graphs can then be manipulated to encapsulate the provenance. To simplify and automate the process of adding and retrieving provenance for data obtained from queries we have developed an application, ProvExplorer, to serve as a workbench for the retrieval and exploration of provenance. The application is written in Java and makes use of the ProvToolbox API (Moreau 2019). ProvExplorer offers a GUI with a PROV-N (a human readable provenance notation) editor. The PROV-N can be viewed as a provenance graph. To encapsulate provenance data, operators can then be applied as policies.

The current system facilitates provenance users encapsulating (and thereby simplifying) their own provenance data. The potential to obfuscate (hide) provenance data will still be an important part of the process on the data owner's side, but the central focus of the system - that of providing relevant data to decision makers - requires the automation of graph simplification and the facility to expand simplified nodes as desired.

Query Repair

When a query fails, CHAIn uses structural semantic matching to repair the query with respect to the target data source and the queries are rewritten accordingly (McNeill et al. 2014; Giunchiglia et al. 2008). The matching part of the process is done by the SPSM algorithm (Giunchiglia et al. 2008), which performs pairwise matching of structured terms. SPSM combines structural matching with ontology-based matching, where existing ontologies and lexicons, such as SUMO (Niles and Pease 2001) and WordNet (Fellbaum 1998), as well as domain-specific ontologies where available, are used to determine how similar different words and terms are. Matching can usually be done in multiple ways and matches will rarely be perfect, so the similarity score is calculated to indicate the closeness of each match. For each match SPSM returns the similarity and a set of mappings between the different components of the two terms. The mappings are used to write a repaired version of the query which can be run on the datasource, and the repaired query, similarity score and mappings are returned.

SPSM is an expensive process, and it is not feasible to do it between a single query and every possible datasource. CHAin therefore performs a filtering step first, narrowing down the datasource schemas to a subset of likely candidates. Related terms are computed based on the SUMO and WordNet ontologies. In Figure 2 the schemas for the query and for the top ranked responses are all represented by the same predicate "sensor", and therefore these data schemas pass the narrow-down step and proceed to SPSM matching.

The schema-matching part of the process matches first-order terms: that is, terms of the form
$predicate(Arg, Arg, ..., Arg)$,
where each Arg may itself be a function. This process is therefore applicable to data formats that can be translated into this format. This is a very general format which includes a vast number of common representations. Currently, the CHAIn system can be used for SPARQL queries to RDF datasources and for SQL queries to RDB datasources, and may be extended to hierarchical and tabular structures such as JSON and spreadsheet tables.

DATA-DRIVEN DEVELOPMENT AND EVALUATION

It is important to develop the system with reference to plausible - ideally real - data that gives scope for both the matching and provenance side of the system. This allows us to base the development on plausible case studies and to carry out realistic evaluations on the resulting system. Currently, there is a paucity of data sources which contain deep, interesting provenance data. In part this is because tools to exploit that provenance are only now being developed. Fortunately, we have been able to work with the Newcastle Urban Observatory[3] (UO). The UO is an ongoing UKRIC project involving, among others, Newcastle University that provides the largest set of publicly available real time urban data in the UK. The Newcastle project covers city centre and the suburbs. More than 50 data types organised in 12 themes such as air quality, traffic, weather, are gathered from sensors across the city. A RESTful API is made available for developers allowing data to be downloaded in JSON or CSV format.

Although the UO does not address the issue of capturing provenance specifically, it does capture some data that can be used to verify the quality of data. As per our running example, we are working primarily with sensor data for sensors that are involved in counting cars and people. The process used for producing the counts make for an interesting pipeline for which the quality of data might be questioned by decision makers. For instance, a query can

[3] http://www.urbanobservatory.ac.uk/

be made for the number of cars that were detected by a sensor in a specific location at a specific time. Questions such as the following might come to mind when the results are retrieved:

1. How are these counts generated?
2. How are the counts affected by adverse weather and light conditions?
3. What happens if one car partially obscures another?

As well data as with good provenance data attached, we need data that comes from multiple similar data sources so that we can develop and evaluate the matching aspects of the system. The UO supports three different opportunities for data matching. First, there is some variability within the UO data sources. The UO gathers data from different sources. Sensors are of different types and similar data is returned from sensors provided by different services with varying data structures and semantics. In our use case information about traffic flow may be obtained from cameras, satellite images or electromechanical sensors, in different but possibly overlapping locations. Second, the generality of the CEM-DIT system can be tested by posing queries which are based on other city data sources such as NYC Open Data Repository[4], and attempting to repair these queries with CEM-DIT so that they run on UO data. Third, evaluation can be performed via synthetic queries which mimic the variability of real-life queries. We have developed a system, CRPTR for CHAIn, which takes queries which will run on an existing knowledge source and generates wide variety of plausibly corrupted queries. For evaluation we will create multiple corrupted queries and attempt to repair them with CEM-DIT so that they run on UO data.

Evaluation Aims

Evaluation for a system such as CEM-DIT is a tricky business. Ultimately, we want to ask the question *when decision makers are able to access a wide variety of data through the CEM-DIT system, and use the system to facilitate their understanding of and trust in this data, do they make better decisions than if they do not have access to such automated support tools?* Quite apart from determining how we evaluate 'better' decisions, direct access to decision makers in a simulated context that is meaningfully similar to a real crisis situation is expensive and difficult. It is essential that we carry out an evaluation that demonstrates the usability and value of the system before it is used in simulations with real responders.

Our concern at the moment is to evaluate two aspects of the system: (*i*) does the underlying technology provide results that are appropriate; (*ii*) does the system allow decision makers to interact with these results in a useful way.

- (*i*) Determining whether the results returned are appropriate means:
  - *are the matches returned relevant to the queries asked, and is the ranking a good reflection of the differing quality of the match?* Determining this is not straightforward as, in most cases, there is no gold standard against which we can judge our results, and there is some amount of subjectivity in assessing whether one rephrasing of a query is 'better' than another. There are various attempts in the matching community to create gold standards for evaluation, for example the Ontology Alignment Evaluation Initiative[5]. Whilst this initiative does not address the same matching problem as we are, we can use the test sets generated by this initiative to support evaluation. In addition, CRPTR for CHAIn corrupts data sets in a variety of ways to create plausible mismatched sets with a pre-existing gold standard, and hence facilitates evaluation.
  - *is the decision maker able to immediately access a simple version of the provenance data and then, if desired, use the system to access all the provenance information available?* Evaluating this is a much simpler prospect, requiring a definition of what an acceptable initial compression of the provenance data would be, and a demonstration that access to complete available provenance data was always possible.
- (*ii*) Since developing a sophisticated GUI that would be usable in the field is outside the scope of our current work, investigating the second point will involve getting decision makers who understand the data, and in particular the provenance, to give us feedback on the usability of the system.

We are currently working with the UO to develop a suitable evaluation scenario with multiple mismatched data sources and relevant accompanying provenance data generated.

[4] https://opendata.cityofnewyork.us/
[5] http://oaei.ontologymatching.org

NEXT STEPS

The majority of the underlying technology for the system described above is already implemented, but some steps remain of both theoretical development and implementation before the system described above is fully realised.

- **Extending the GUI to support the full functionality of the system.** The current project will include extending our existing GUI, which focusses on interaction with provenance data, to allow full visualisation of the matching data as illustrated in Figures 2 and 3. Creating a GUI suitable for use in the field is outside the scope of our current project but working closely with decision makers to understand the kind of interface they would need to use such a system is an essential part of bringing such technology to the field and something we intend to focus on in future.
- **Extension of the matching system to facilitate the dynamic reorganisation of matches based on user feedback.** The scoring algorithm of the matching system needs to be updated so that when matches are downgraded by the decision maker the downgrade is propagated to other relevant matches, and so that potential matches are removed automatically from the returned results list if they include aspects that decision makers have indicated are unacceptable.
- **Inverting the encapsulating functionality in the provenance system.** ProvExplorer has been designed as a tool for those who own provenance data to be able to control it, allowing them to encapsulate any parts they do not wish to view in detail. CEM-DIT requires this functionality to be inverted, as it requires a simple version of the provenance data to be presented to the user, with the ability to expand that as far as the user requires, or is possible.

CONCLUSIONS

In this paper, we introduced the CEM-DIT system, which is designed to support decision makers during crises by allowing them to easily access, understand and trust data from multiple heterogeneous data sources, which may be unknown and/or partially trusted. The theoretical underpinnings of the system and significant components of the implementation are in place, and we are currently working on the full implementation of the system.

REFERENCES

Alper, P., Belhajjame, K., and Goble, C. A. (2016). "Automatic vs manual provenance abstractions: mind the gap". In: *arXiv preprint arXiv:1605.06669*.

Burel, G., Piccolo, L., Meesters, K., and Alani, H. (2017). "[D]o[RES] - A Three-Tier Ontology for Modelling Crises in the Digital Age". In: vol. 2017-. Information Systems for Crisis Response and Management, ISCRAM, pp. 834–845.

Fellbaum, C., ed. (1998). *WordNet: an electronic lexical database*. MIT Press.

Fischer, D., Posegga, O., and Fischbach, K. (2016). "Communication Barriers in Crisis Management: A Literature Review". In: *24th European Conference on Information Systems, ECIS 2016*. Association for Information Systems.

Freitas, D. P., Borges, M. R., Vivacqua, A. S., and Carvalho, P. V. (2016). "Communication Channels Among Various Roles During Crisis Response". In: Information Systems for Crisis Response and Management, ISCRAM.

Galton, A. and Worboys, M. (2011). "An ontology of information for emergency management". In: *Proceedings of 8th International Conference on Information Systems for Crisis Response and Management*.

Gehani, A. and Tariq, D. (2011). "SPADE: Support for Provenance Auditing in Distributed Environments". In: *SRI International*.

Giunchiglia, F., McNeill, F., Yatskevich, M., Pane, J., Besana, P., and Shvaiko, P. (2008). "Approximate Structure-Preserving Semantic Matching". In: *On the Move to Meaningful Internet Systems: OTM 2008*. Springer, pp. 1217–1234.

McNeill, F., Gkaniatsou, A., and Bundy, A. (2014). "Dynamic Data Sharing from Large Data Sources". In: *Proceedings of 11th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2014)*.

Missier, P., Bryans, J., Gamble, C., Curcin, V., and Danger, R. (2014). "ProvAbs: model, policy, and tooling for abstracting PROV graphs". In: *International Provenance and Annotation Workshop*. Springer, pp. 3–15.

Moreau, L. (2019). *The Open Provenance Website*.

Moreau, L., Missier, P., Belhajjame, K., B'Far, R., Cheney, J., Coppens, S., Cresswell, S., Gil, Y., Groth, P., Klyne, G., et al. (2013). *PROV-DM: The PROV Data Model*. Tech. rep. World Wide Web Consortium.

Niles, I. and Pease, A. (2001). "Towards a Standard Upper Ontology". In: *Proceedings of the International Conference on Formal Ontology in Information Systems - Volume 2001*. FOIS '01. Ogunquit, Maine, USA: ACM, pp. 2–9.

Paulus, D., Meesters, K., Walle, B. van de, Boersma, K., and Tomaszewski, B. (2018). "Turning Data into Action: Supporting Humanitarian Field Workers with Open Data". In: *Proceedings of the 15th International ISCRAM Conference*.

Prat, N. and Madnick, S. (2008). "Measuring Data Believability: A Provenance Approach". In: *Proceedings of the 41st Annual Hawaii International Conference on System Sciences (HICSS 2008)*, pp. 393–393.

Quesada Real, F., McNeill, F., Bella, G., and Bundy, A. (2017). "Improving Dynamic Information Exchange in Emergency Response Scenarios". In: *Proceedings of 14th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2017)*.

Rietjens, S. J., Verlaan, K., Zaalberg, T. W. B., and De Boer, S. J. (2009). "Inter-Organisational Communication in Civil–Military Cooperation During Complex Emergencies: A Case Study in Afghanistan1". In: *Disasters* 33.3, pp. 412–435. eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-7717.2008.01081.x.

Ruiz-Zafra, A., Núñez, A.-G., Penadés, M., Canós, J., and Borges, M. (2014). "[SUCR]E: Supporting Users, Controllers and Responders in Emergencies". In: *ISCRAM 2014 Conference Proceedings - 11th International Conference on Information Systems for Crisis Response and Management*. The Pennsylvania State University, pp. 255–259.

Shamoug, A., Cranefield, S., and Dick, G. (2018). "Information Retrieval for Humanitarian Crises via a Semantically Classified Word Embedding". In: vol. 2018-. Information Systems for Crisis Response and Management, ISCRAM, pp. 132–144.

Simas, F., Barros, R., Salvador, L., Weber, M., and Amorim, S. (2017). "A Data Exchange Tool Based on Ontology for Emergency Response Systems". In: *Research Conference on Metadata and Semantics Research*. Springer, pp. 74–79.

Real-time Emergency Response through Performant IoT Architectures

Claudio Arbib
University of L'Aquila
claudio.arbib@univaq.it

Davide Arcelli
University of L'Aquila
davide.arcelli@univaq.it

Julie Dugdale
University of Grenoble Alps
julie.dugdale@imag.fr

Mahyar T. Moghaddam
University of L'Aquila
mahtou@univaq.it *

Henry Muccini
University of L'Aquila
henry.muccini@univaq.it †

ABSTRACT

This paper describes the design of an Internet of Things (IoT) system for building evacuation. There are two main design decisions for such systems: *i)* specifying the platform on which the IoT intelligent components should be located; and *ii)* establishing the level of collaboration among the components. For safety-critical systems, such as evacuation, real-time performance and evacuation time are critical. The approach aims to minimize computational and evacuation delays and uses Queuing Network (QN) models. The approach was tested, by computer simulation, on a real exhibition venue in Alan Turing Building, Italy, that has 34 sets of IoT sensors and actuators. Experiments were performed that tested the effect of segmenting the physical space into different sized virtual cubes. Experiments were also conducted concerning the distribution of the software architecture. The results show that using centralized architectural pattern with a segmentation of the space into large cubes is the only feasible solution.

Keywords

Emergency Evacuation, IoT, Software Architecture, Network Optimization, Queuing Network.

INTRODUCTION

Building evacuation plans are generally designed as static maps in which routes are pre-specified for people to follow when an emergency happens. However, such maps may increase risks due to their lack of real-time data consideration, e.g. emerging dangerous areas, congestion and obstacles. To obtain such a real-time situational awareness the building may be equipped with IoT components. IoT is defined as the internal/external communication of intelligent components via internet in order to improve the environment through providing smarter services (Muccini and Moghaddam 2018). An IoT infrastructure is generally composed of sensing, computation and actuation components that are distributed over the area. The way these components are related and combined together is specified by *software architectures*. IoT architectures can support rules for quicker and safer evacuation by tracking people in a building, detecting possible congestion, and updating the best safety paths. Consequently, the evacuation time under changing emergency conditions can be minimized.

Important questions are: *what kind of reasoning algorithm should an IoT-based emergency evacuation system use? How should it be embedded inside an IoT software architecture?* Some previous research have tried to address these questions. Regarding the logic, previous research (Arbib, Muccini, et al. 2018) (Arbib, Moghaddam, et al.

*corresponding author.
†All authors contributed equally to this work.

2019) found that the IoT system may be designed in such a way as to provide security staff with information to continuously monitor the shortest time required to evacuate people in a building. In addition, the occupants were shown the best paths to evacuate the building. Other research (Muccini, Arbib, et al. 2019) developed a network flow algorithm that can be used in a computer simulation for designing buildings, and also in real-time building evacuation. The authors (Muccini, Spalazzese, et al. 2018) (Muccini and Moghaddam 2018) further argued that the flow algorithm can be embedded into the core of IoT reference architectures. The algorithm decomposes both the space (building plan) and the time dimension into finite elements: *unit cells* and *time slots*. The space element is monitored by IoT sensors, whose data are constantly feed into the algorithm. The algorithm can be run on one centralized components or on distributed collaborating controllers. However, this may impact not only the quality of the solution provided by the system in terms of performance, but also the system's functionality.

This paper extends previous domain knowledge by addressing the following aspects: *i)* the operational delay (evacuation time) and computational delay (CPU time) are calculated by the algorithm, but they have never been practically used in an IoT system; *ii)* the feasibility of running the algorithm in distributed processing and storage (P&S) components and any possible delays needs to be assessed; *iii)* the impact of changing the granularity of the space cells on IoT system functionality needs to be analyzed.

This paper makes the following contributions:

- Queuing network models for an IoT software architecture: we introduce a novel set of queuing network models that can be exploited for estimating performance of IoT systems adhering to IoT architectural patterns, in order to support architectural decisions.
- Algorithm distribution feasibility: we present the algorithm and assess its reaction to time- and space-decomposition.
- Cell size optimization: we present an optimization model for deciding on a good cell size.
- Evaluation: we evaluate our work by using the real case study of an exhibition venue, in the Alan Turing building, in Italy, with real data. Using various techniques and simulations we design the best internal building layout to handle emergency evacuations.

To the best of our knowledge, this is the first attempt to fill the gap between IoT software architectures, optimization algorithms for minimizing delays and performance modelling and analysis practices, in the context of emergency evacuation.

OVERVIEW

There is a large body of previous work in the three topics that shape our research, namely IoT software architecture, queuing networks, and optimization algorithms. However, their application to the emergency management has been rarely explored.

Related Work

Prior work has addressed problems related to software architecture modeled by queuing network. El Kafhali et al (El Kafhali and Salah 2018) proposed an analytic model for a fog/cloud-based Medical IoT system to show how to reduce the cost of computing resources while guaranteeing performance constraints. They used the QN concept to predict the system response time and estimate the minimum required number of P&S resources to meet the service level agreement. However, they do not provide any kind of high or low level architectural modeling. Huang et al (Huang et al. 2018) propose a theoretical approach of performance evaluation for IoT services, which provides a mathematical prediction on performance metrics at the design phase before system implementation. The authors formulate an atomic service by a queuing system in order to model IoT systems by a queuing network and obtain performance metrics. Whilst using QN, this paper does not address any modeling based on software architecture to be assessed by performance indices. Whilst few related works have been found on IoT systems modeling with QNs, we did not find any previous work on modeling emergency evacuation systems by QNs.

IoT software architectures

IoT architectures are generally composed of three main layers (Muccini and Moghaddam 2018) namely *Perception*, *Processing and Storage (P&S)*, and *Application*:

- The Perception layer represents the IoT physical sensors that collect information. For emergency management, the Perception Layer hosts a large number of different types of sensors, e.g. temperature, smoke and movement detectors.
- The Application layer determines the class of services provided by the IoT system. For emergency management, the Application Layer hosts a large number of different types of actuators, e.g. dashboards, evacuation signs and alarms.
- The P&S layer is the central entity of an IoT system that stores and analyses data gathered by the perception components to be accessed by other entities for their applications. Based on the P&S design philosophy, this layer can be divided into various sub-layers to set up the *IoT patterns* as follows:

Centralized. In a centralized pattern, data coming from the perception layer are processed by a central component that makes decisions on actuation. This central component can either be a local controller or, for massive P&S requirements, the cloud. Based on this pattern, if a device wishes to use an IoT service, it must connect to the central P&S component. A centralized architecture simplifies things through a central implementation of analysis and planning algorithms.

Collaborative. In this pattern, data are processed and stored separately (locally and/or remotely) but with the potential collaboration of other local/remote P&S components of the IoT system. In this pattern, a network of local intelligent components can communicate in order to form and empower IoT services. The advantage is that, should a local P&S component fail, a service would still be provided.

Given the above, we designed a set of QNs for IoT architectures that are described in following sections.

Queuing networks

In order to estimate performance indicators and avoid the performance degradation issues associated with IoT architectural patterns, we rely on Queuing Network (QN) models. QNs have emerged as powerful instruments to model and estimate the performance of hardware and software systems. They ground on theoretical foundations based on an algebraic approach to computer system modelling proposed by Lazowska in 1984 (Lazowska et al. 1984), where the computer system is represented as a network of delay and/or queuing *stations* (i.e. topology of the QN). Different *classes of jobs* may flow through the QN, each representing different types of user requests (i.e. dynamics within the QN). While flowing through the QN, each task requires a certain amount of service, namely *service demand* (mentioned as *CPU time* in this paper) to each visited station, depending on the job class the task belongs to. It is worth mentioning that, service demands represent input parameters that must be specified during QN design. Beside service demands, *workload intensities* must be specified, that is the rate at which tasks of each job class enter the QN. For example, a request (of a certain job class) every 2.5 seconds.

Once a QN has been designed, it can be solved analytically or by simulation, carrying out performance indices of interest such as system/stations response time and throughput for both the overall system and single classes of jobs.

Algorithm

The building to be evacuated is represented as a graph $G = (V, A)$ with nodes corresponding to the unit cells i obtained by embedding the building into isometric square grids. Cell 0 conventionally represents the outside of the building, or in general a safe place. The arcs of G correspond to passages between adjacent cells: the passage has full capacity if cells share a boundary uninterrupted by walls, and a reduced capacity otherwise. With no loss of generality, arcs are supposed directed. Let us denote:

T = $\{0, 1, \ldots, \tau\}$, set of unit time slots;

y_i^t = state of cell $i \in V$ at time $t \in T$, that is, the number of persons that occupy i at t: this number is a known model parameter for $t = 0$ (in particular, $y_0^0 = 0$) and a decision variable for $t > 0$;

n_i = capacity of cell i: this is the maximum nominal number of people that i can host at any time (in particular, $n_0 \geq \sum_i y_i^0$); this amount depends on cell shape and size; if cells are assumed to be uniform one can set $n_i = n$ for all $i \in V, i \neq 0$.

x_{ij}^t = how many persons move from cell i to an adjacent cell j in $(t, t + 1]$: this gives the average speed at which the flow proceeds from i to j;

$c_{ij} = c_{ji}$ = capacity of the passage between cell i and cell j: this is the maximum number of people that, independently of how many persons are in cell j, can traverse the passage in the time unit (independence of cell occupancy means that congestion is not taken into account: this will be considered later).

The flow model uses an acyclic digraph D with node set $V \times T$ and arc set

$$E = \{(i,t) \to (j,t+1) : ij \in A, t \in T\}$$

In other words, D models all the feasible transitions (moves between adjacent cells) that can occur in the building in the time horizon T. Transitions are associated with the x-variables defined above, whereas y-variables define the occupancy of each room (and of the building) over time. In real-time, these values can be periodically obtained by the previously described IoT infrastructure. The x- and y-variables are integers and subject to the following constraints:

$$y_j^t - y_j^{t-1} - \sum_{i:ij\in A} x_{ij}^{t-1} + \sum_{i:ji\in A} x_{ji}^{t-1} = 0 \qquad j \in V, t \in T, t > 0 \tag{1}$$

$$0 \le x_{ij}^t + x_{ji}^t \le c_{ij} \qquad t \in T, ij \in A \tag{2}$$

$$0 \le y_i^t \le n_i \qquad t \in T, i \in V \tag{3}$$

Equation (1) is just a flow conservation law: it expresses the occupancy of cell j at time t as the number y_j^{t-1} of persons present at time $t-1$, augmented by those during interval $(t-1,t]$ that move to j from another cell $i \neq j$, minus those that in the same interval leave cell j for another cell $i \neq j$. Box constraints (2), (3) reflect the limited hosting capability of the elements of G.

Maximizing outflow at a given time. To model the relation between time and people outflow, one can try to maximize the number of persons evacuated from the building within τ:

$$\max \quad y_0^\tau \tag{4}$$

To find the minimum total evacuation time, one can solve an Max Flow Problem for different τ, looking for the least value that yields a zero-valued optimal solution. To reduce computation time, this optimal τ can be computed by logarithmic search. The method can thus provide the decision maker with the Pareto-frontier of the conflicting objectives $\min\{\tau\}, \max\{y_0^\tau\}$. Linearizing arc capacities that is quite standard in applications can be find in our previous work (Muccini, Arbib, et al. 2019).

DESIGNING PERFORMANT ARCHITECTURES FOR EMERGENCY HANDLING

Software Architecture for Emergency

Figure 1 shows an example of an IoT-based environment for emergency response: CCTV cameras detect peoples position and movement that is used to feed the algorithm running in a P&S component. The algorithm decides on the actuation set based on the situation. In normal situations, the system shows, on a tablet, a 2D-representation of the monitored space and shows where crowds are located and how they move at any time. In this mode, the optimal flow algorithm is periodically run to estimate the minimum evacuation time required under current conditions. This value can be used to regulate visitor access to a venue in order to comply with safety conditions. If an emergency happens, in addition to the tablet map, alarm actuators are activated and evacuation signs in each area show the best evacuation routes based on the network model described above.

Figure 2 shows the corresponding software architecture. As depicted, additional sets of sensors can be embedded for emergency detection to further enable controllers to decide about normal or critical mode and activate a special set of actuators. As shown in the upper part of Figure 1, in addition to the computational delay of the P&S component, the sensors take some time to detect peoples position, transmit these data, and display the best evacuation routes. Reducing these delays to a minimum improves the system's functionality: since people can follow the given instructions more quickly and more individuals will be in a better evacuation position at the next monitoring time-spot. It is worth mentioning that reducing the aforementioned delays is a function of software architectural patterns, to be improved by properly relating the IoT components to one another. The following section presents a Queuing Network (QN) method that is designed on top of the software architecture, so as to facilitate assessing the performance of our IoT-based emergency handling system.

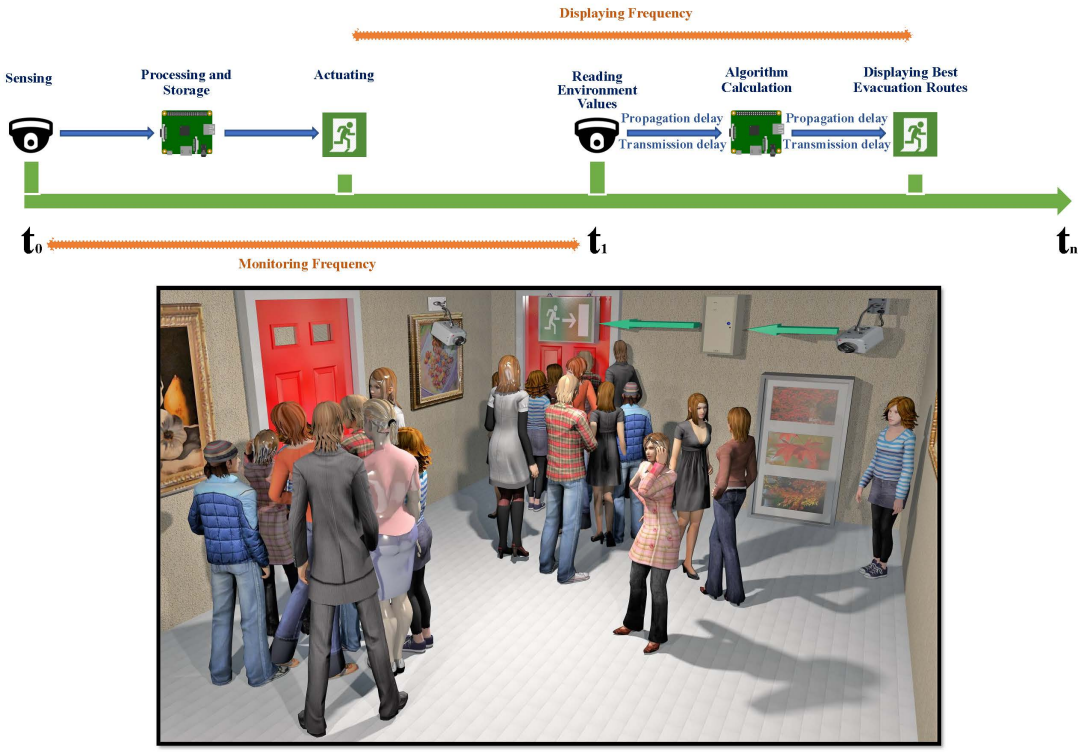


Figure 1. IoT Infrastructure for Emergency Handling.

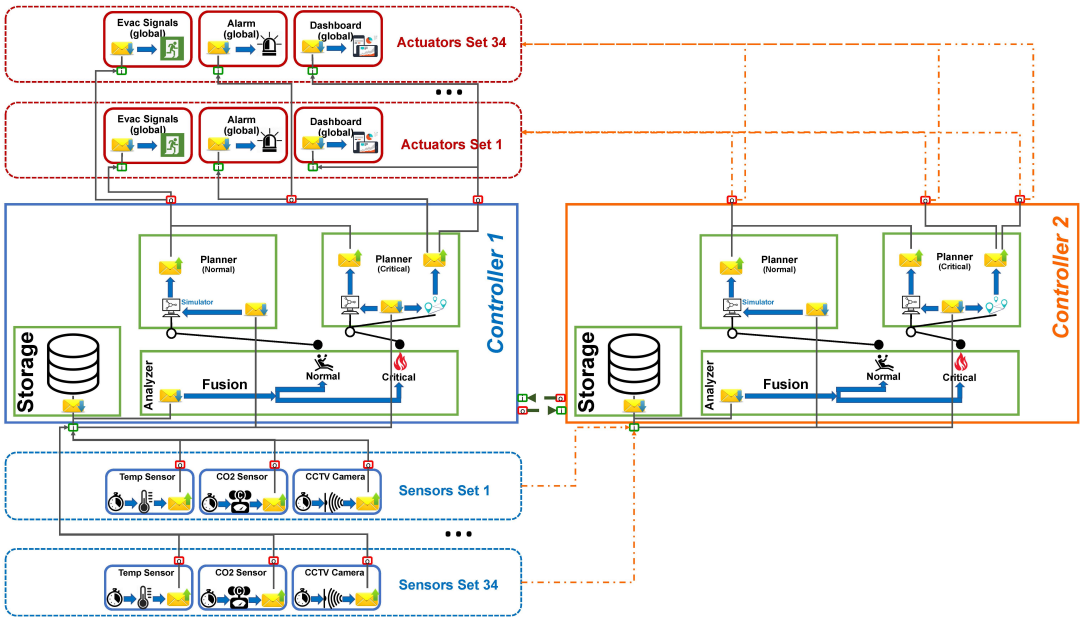


Figure 2. Architectural Patterns. Only Controller 1 Active: Centralized - Both Controllers Active: Collaborative.

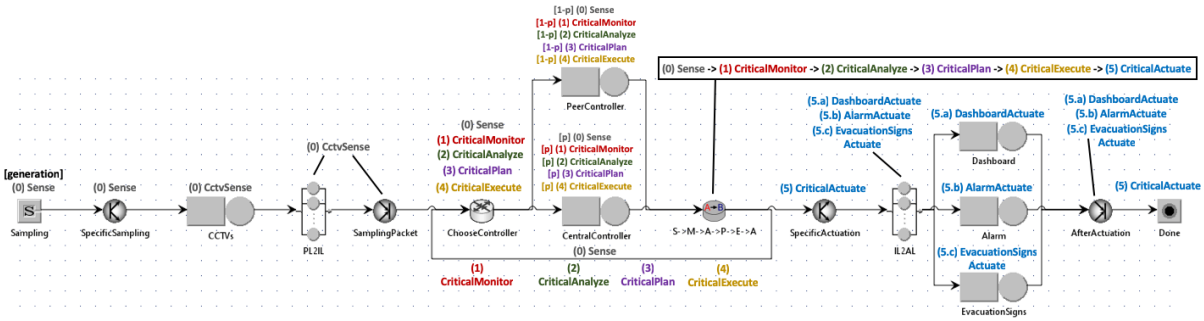


Figure 3. SMAPEA Queuing Network for the Alan Turing building case study.

Queuing Networks for Emergency

Fig. 3 shows a QN representing the performance model that we will exploit later in the paper for our case study. The QN conforms to the architectural patterns of Fig. 2, in fact, from a topological perspective:

- *CCTVs* corresponds to a specific kind of sensors, i.e. cameras.
- *Dashboard*, *Alarm* and *EvacuationSigns*, correspond to the three kinds of actuators.
- *CentralController* and *PeerController* correspond to the two P&S components.
- *PL2IL* and *IL2AL* represent networks between sensors and controllers and between controllers and actuators, respectively.
- The two QN constructs on the left and right of the figure, namely *Sampling* and *Done* represent the entry and exit points of the QN, respectively. In particular, *Sampling* indicates the point where data sampled by sensors is generated and *Done* represents the point where actuation ends.

Concerning dynamics, we devise the following control flow within IoT architectures: *i)* Data are sampled by sensors and forwarded through a network to controller(s); *ii)* A control layer aims at achieving the goal of evacuating people during emergency, through an actuation plan that is forwarded to actuators; *iii)* The actuation plan is implemented by actuators, thus possibly achieving the common goal.

The above control flow can be translated into QN language, by identifying a minimal set of 6 different kinds of tasks within a QN for IoT system performance (namely *SMAPEA* loop), sequentially executed as follows: *1.)* *Sense*: Raw data retrieval. *2.)*Monitor: Raw data aggregation and refinement for analysis at controller level. *3.)*Analyze: Interpretation of monitored data. *4.)*Plan: Building an actuation strategy. *5.)*Execute: Pre-processing the actuation strategy towards actuation. *6.)*Actuate: Practically undertaking the actuation by implementing the planned execution.

In order to implement the SMAPEA loop, a *class-switch* that transforms each SMAPEA task to a subsequent task is introduced (see the $S \rightarrow M \rightarrow A \rightarrow P \rightarrow E \rightarrow A$ element of Fig. 3). Moreover, routing probabilities for the switch must be properly defined. In particular, right after the switch, any SMAPEA task type is routed back to controllers through the *ChooseController* router (except *Actuate* tasks that are routed to *IL2AL* for actuation). By exploiting a probability-based routing strategy for *ChooseController* both Centralized and Collaborative patterns can be implemented, in fact the former may route any task to *CentralController*, whilst the latter may route tasks to *CentralController* or *PeerController* with 50% probability.

Notice that, in the QN of Fig. 3, fork/join nodes have been introduced, namely *SpecificSampling* (fork), *SamplingPacket* (join), *SpecificActuation* (fork), *AfterActuation* (join), aimed at modelling the fact that *Sense* and *Actuate* tasks involve the specific sensor and actuator sets, respectively. For example, each *CriticalActuate* task is split into three new tasks, namely *DashboardActuate*, *AlarmActuate* and *EvacuationSignsActuate*, because in case of emergency *i)* the best evacuation paths must be displayed on dashboard, *ii)* an acoustic alarm must be triggered and *iii)* evacuation signs must be properly turned on.

Algorithm Settings for Emergency

Cell Size Setting and its Impact on Architecture.

The cell size has an obvious effect on the resulting spatial patterns, and consequently on both the computational efficiency and model accuracy: the larger the cell, the fewer vertices in G and the lower the refresh frequency

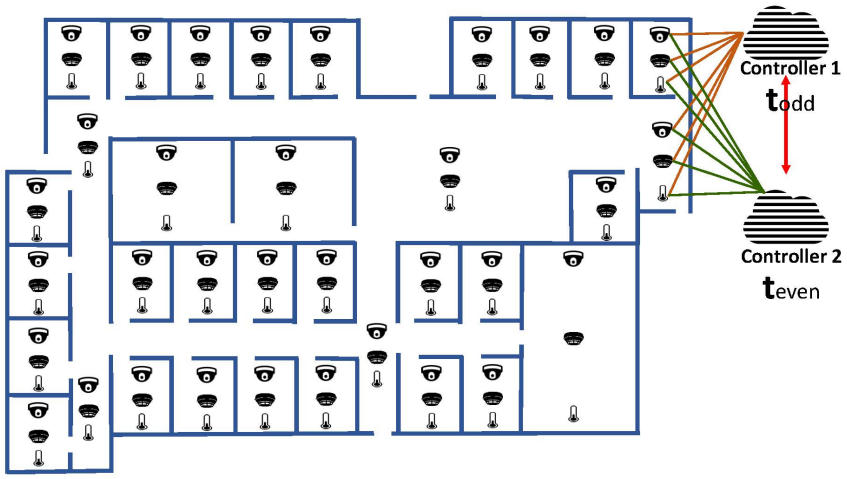


Figure 4. Alan Turing Building IoT Infrastructure.

at which people's positions are updated. Given the speed at which people move and the data that are acquired, relatively low refresh frequencies are not an issue. Instead, partitioning each room into identical cells may result in a huge network with consequently high CPU time. This issue has a direct impact on software architectural patterns since an operation which requires a huge amount of processing time on a low capacity machine is not suitable for real-time applications. Therefore it should be processed on a more powerful (potentially remote) P&S component.

In general, one can approximate the diverse room shapes by $a \times b$ rectangles as large as possible, while still minimizing any consequent error. Various ways can be adopted to measure approximation error: the most natural is the difference between real and approximated room area, in which case, for room k of size $p_k \times q_k$, the error is given by

$$e_k(a,b) = q_k[p_k \mathrm{mod}(a)] + p_k[q_k \mathrm{mod}(b)] - [p_k \mathrm{mod}(a)][(q_k \mathrm{mod}(b)]$$

As we need isometric cells and look for a uniform approximation, we set $a = b$ and find a minimizing $\max_k\{e_k(a,a)\}$, meanwhile limiting the total number of approximating cells to some predefined m: hence we choose among the values of a that fulfill $\sum_k \lfloor p_k/a \rfloor \lfloor q_k/a \rfloor \leq m$. A brief description of the method implementation is presented in the Application section.

Time and Space Decomposition Setting and its Impact on Architecture. In order to run the algorithm in distributed P&S components (collaborative pattern), we assessed the space- and time- decomposition feasibility. In the former case, we can give, for instance, two controllers the responsibility of two distinct areas, and let them share border information. Since the global objective cannot generally be satisfied by summing up two local objectives (that is running the algorithm in two local controllers instead of a central one), this method mostly leads to a non-optimal solution obtained by "gluing" together the two distinct areas. In the latter case, we conjectured that the optimal flow obtained at time t can be extended to $t + 1$ and stay optimal. This means that, for instance, one P&S element is in charge of solving the algorithm for t_{even}, and for t_{odd} (Figure 6) whilst sharing a level of data. Assessing this decomposition and taking into account our main requirement of optimally is described in the Application section. Here we can observe the ability of the algorithm to be run in a distributed way or centralized.

APPLICATION

Our proposed model has been applied to the evacuation of the Alan Turing building, in Italy, which is sometimes used for exhibitions. The considered building consists of 29 rooms, 4 main corridors and 34 sets of IoT sensors and actuators (Figure 4). In order to investigate our approach we address four research questions. The first two questions are centered around the algorithm and its levels of granularity and distribution:

- **RQ1**: what are the best cells sizes to divide the building surface, and how does the size affect the evacuation times and computational delays?
- **RQ2**: does running the algorithm in a time-decomposed way increase or decrease the computational and operational delays? What are the designed software architectures corresponding to these results?

The next two research questions are focused on the software system delays (using Queuing Networks):

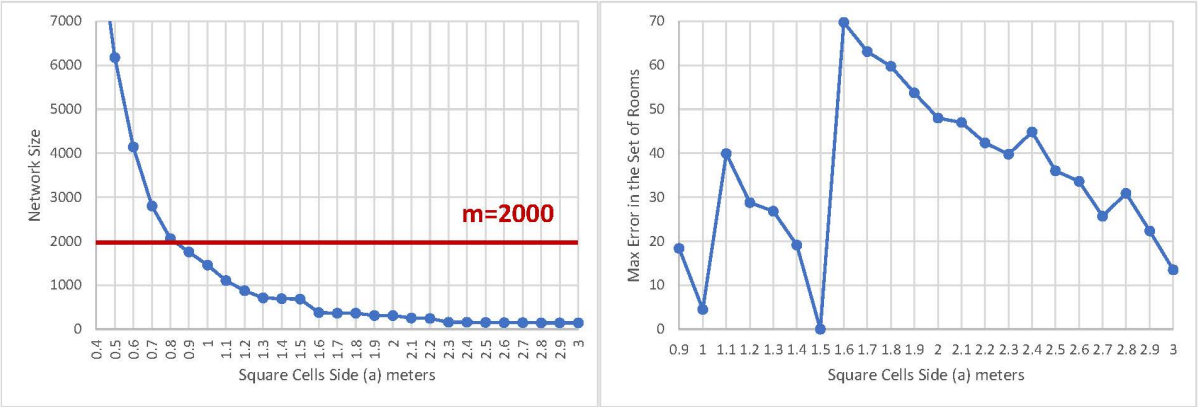


Figure 5. Optimal cell size: maximum error (right) and network size as a function of cell size (left).

- **RQ3**: what level of delay is tied up with each QN model adhered to architectural patterns?
- **RQ4**: what software architectural design reduces delays to make it usable for real-time applications?

Answers to RQ1: cellular approximation of physical space

We split each room in unit cells, each behaving as a (virtual) square room that can be traversed in a unit time slot. In practice, we embedded the building plan into a square grid as shown in Figures 6 and 8. To decide the cell size, we look at both the error introduced by room approximation and the number of nodes in the resulting graph G. The latter is in an inverse proportion of cell size (left diagram in Figure 5); the former varies irregularly with cell size (right diagram of Figure 5). We considered square cells up to 3×3 meters (the short edge of the smallest room) and allowed no more than 2000 nodes of G; then we selected the size that minimizes the largest error for all rooms. The reason of considering such a big maximum network size is to assess the impact of increasing the number of nodes on CPU time and consequently, on the software architectural pattern. As shown in Figure 5, 1.5×1.5 cells (Figure 8) give the best approximation (no error) and involve 687 graph nodes (Figure 9). With 3×3 cells (Figure 6) the error rises to 13.5 but G contains only 144 nodes (Figure 7). Summarizing, 3×3 leads to larger error but less CPU time; conversely, 1.5×1.5 causes larger CPU time but no error. We tested scenarios with both cell sizes in order to find the best efficiency/accuracy compromise.

Simulation. Simulations were first run for both cell sizes. The simulation code was written in the OPL language and problems were solved by CPLEX version 12.8.0. All experiments were run on a Core i7 2.7GHz computer with 16Gb of RAM memory under Windows 10 pro 64-bits. In all tests, we computed the minimum time required for 264 persons, randomly distributed in the building rooms, to reach a safe place. This datum comes from an experiment performed in the Alan Turing during the *the Researchers Night* event, when the IoT system recorded the simultaneous presence of 264 people in the building as a peak value. We solved problem (1-4) for $\tau = 1, 2, \ldots$ until a solution of value 264 was found.

To get a reliable model, some more parameters such as walking velocity under various conditions, door entrance capacities and room capacities must be set to numbers that reflect reality. We set these model parameters based on a literature review (Table 1).

Table 1. Evacuation Model Parameters

Model Parameter	Assigned Value
Walking Velocity	1.2 m/s (Ye et al. 2008)
Door Capacity	1.2 $p/m/s$ (Daamen and Hoogendoorn 2012)
Cell Capacity	1.25 p/m^2 (Uk Fire Safety)

Table 2 reports the number of evacuees at each τ and the computation time of each solution step. Computation is done for both *low-* and *high-resolution* networks (respectively, 3×3 and 1.5×1.5 cells). With the low-resolution network, we get the evacuation and CPU times shown in Table 2 left: in terms of evacuation, everyone has reached a safe place in 55 seconds; on the other hand, computation requires 2.33 seconds in the worst case, and is therefore

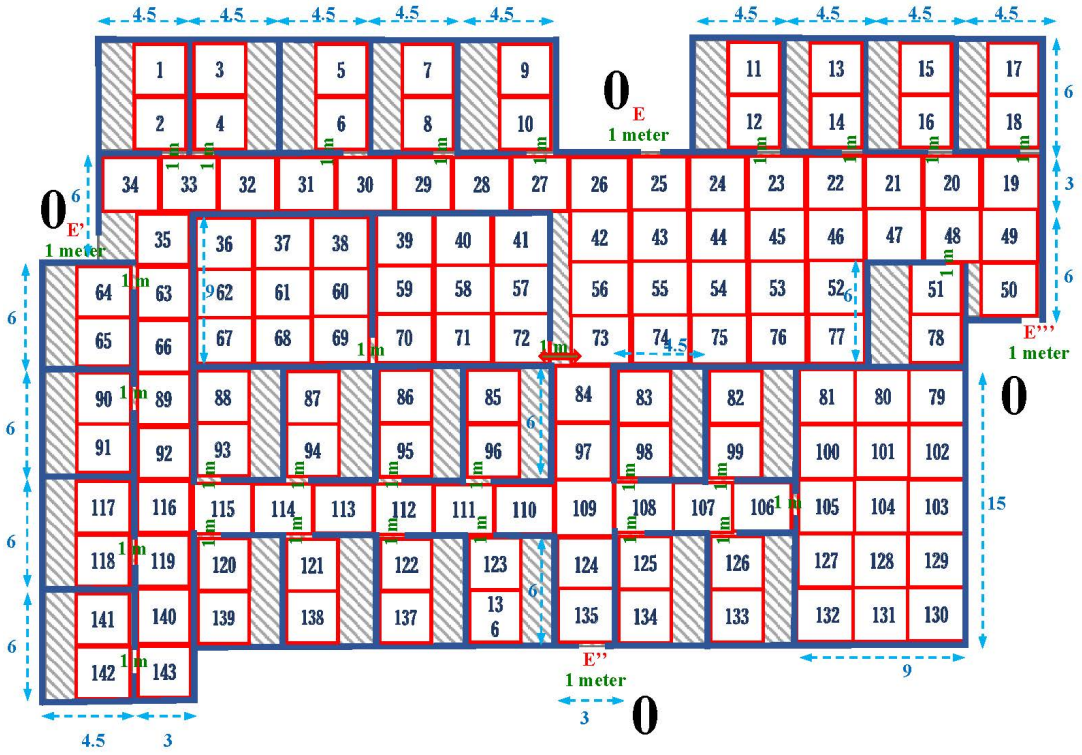


Figure 6. Plan embedding the Alan Turing building into square grids with a low resolution: 3×3 cells. The area that is not covered by cells (error) is shown in gray.

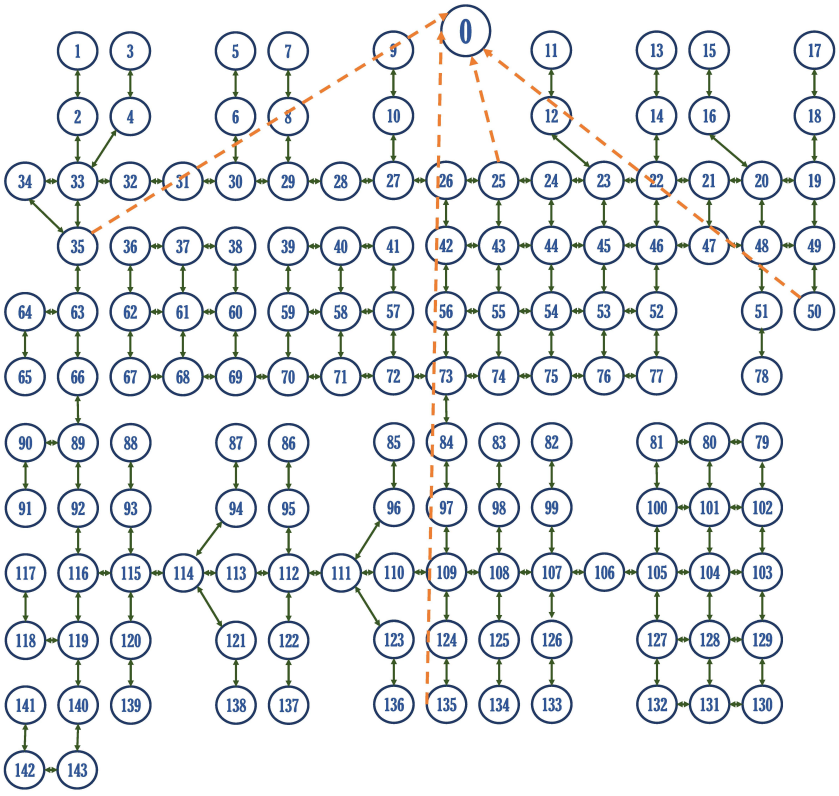


Figure 7. Network associated with the plan of Figure 6.

totally compliant with real-time applications. Evacuation and CPU times for the high-resolution network are reported in Table 2 right. We see that everyone has reached a safe place in 98'75". CPU time is now much larger (382.24 seconds in the worst case) and the model appears inappropriate for real-time use, unless additional computational resources are deployed. Hence we can conclude that sufficient accuracy is obtained using the low resolution network.

Table 2. Evacuation and computation time: *a*) 3×3 **cells (time slots of 2.5 seconds);** *b*) 1.5×1.5 **cells (time slots of 1.25 seconds).**

$\tau(a)$	evacuees (a)	CPU Time (a)	$\tau(b)$	evacuees (b)	CPU Time (b)	$\tau(b)$	evacuees (b)	CPU Time (b)
1	12	0.48 sec	1	6	1.85 sec	41	207	79.10 sec
2	24	0.45 sec	2	12	1.99 sec	42	209	84.37 sec
3	36	0.50 sec	3	18	2.10 sec	43	210	87.07 sec
4	48	0.53 sec	4	24	2.35 sec	44	212	94.39 sec
5	60	0.59 sec	5	30	2.90 sec	45	213	95.04 sec
6	72	0.62 sec	6	36	3.21 sec	46	215	97.86 sec
7	84	0.66 sec	7	42	3.72 sec	47	216	98.71 sec
8	96	0.71 sec	8	48	4.18 sec	48	218	105.83 sec
9	108	0.79 sec	9	54	5.18 sec	49	219	120.60 sec
10	120	0.88 sec	10	60	5.53 sec	50	221	125.50 sec
11	132	0.97 sec	11	66	6.27 sec	51	222	130.07 sec
12	144	1.02 sec	12	72	6.76 sec	52	224	128.54 sec
13	156	1.11 sec	13	78	7.92 sec	53	225	138.54 sec
14	168	1.16 sec	14	84	8.76 sec	54	227	139.20 sec
15	180	1.42 sec	15	90	10.10 sec	55	228	154.73 sec
16	192	1.60 sec	16	96	10.54 sec	56	230	160.65 sec
17	204	1.76 sec	17	102	12.38 sec	57	231	161.58 sec
18	216	1.82 sec	18	108	14.19 sec	58	233	160.01 sec
19	228	1.86 sec	19	114	15.17 sec	59	234	171.88 sec
20	240	2.12 sec	20	120	17.36 sec	60	236	169.26 sec
21	252	2.29 sec	21	126	19.26 sec	61	237	178.87 sec
22	264	2.33 sec	22	132	21.55 sec	62	239	182.49 sec
			23	138	23.50 sec	63	240	201.91 sec
			24	144	24.98 sec	64	242	205.39 sec
			25	150	27.67 sec	65	243	240.93 sec
			26	156	30.12 sec	66	245	213.88 sec
			27	162	34.03 sec	67	246	216.48 sec
			28	168	36.00 sec	68	248	216.67 sec
			29	174	38.31 sec	69	249	230.26 sec
			30	180	40.06 sec	70	251	310.11 sec
			31	186	38.93 sec	71	252	256.64 sec
			32	192	43.35 sec	72	254	329.78 sec
			33	195	47.16 sec	73	255	324.49 sec
			34	197	51.70 sec	74	257	337.55 sec
			35	198	55.31 sec	75	258	348.49 sec
			36	200	63.31 sec	76	260	300.19 sec
			37	201	66.90 sec	77	261	381.83 sec
			38	203	67.27 sec	78	263	382.24 sec
			39	204	71.91 sec	79	264	323.34 sec
			40	206	75.90 sec			

Answers to RQ2: Time Decomposition

Table 3 gives the number of evacuees at each τ and the computation time of each solution step corresponding to time-decomposed networks (collaborative P&S). With a time-decomposed simulation of 3×3 cells, we obtain the evacuation and CPU times in Table 3 left: in terms of evacuation, everyone has reached a safe place in 75 seconds, however computation requires 0.58 seconds in the worst case, and is therefore compliant with real-time applications. Compared with continuous simulation (central P&S) of the same case that is presented in Table 2 left, whilst CPU time is now significantly reduced, the optimal evacuation time is increased by 36 percent. Looking at the time-decomposed simulation results for 1.5×1.5 cell (Table 3 right), CPU time is decreased by at least 123 percent (being 3.11 seconds in the worst case) and the evacuation time remained constant.

Hence, for a high resolution time-decomposed network: whilst the operational delay remains constant, the computational delay improves significantly. However total response time should be observed since the quicker sampling rate tied up with high resolution may cause a negative impact. For a low resolution time-decomposed network: whilst the computational delay decreases, the evacuation delay (that has a priority over all other delays) increases: so that running the algorithm in a collaborative architecture is not recommended, regardless of melioration/deterioration of total response time.

Taking into account the result of this subsection and keeping evacuation time and CPU time as inputs, the following subsection practically assesses, in terms of total response time (delay), the quality of proposed architectural patterns with respect to four different scenarios, resulting from the different combinations of architectural patterns designed to handle emergency situations:

Figure 8. Plan embedding the Alan Turing building into square grids with a high resolution: 1.5×1.5 **cells.**

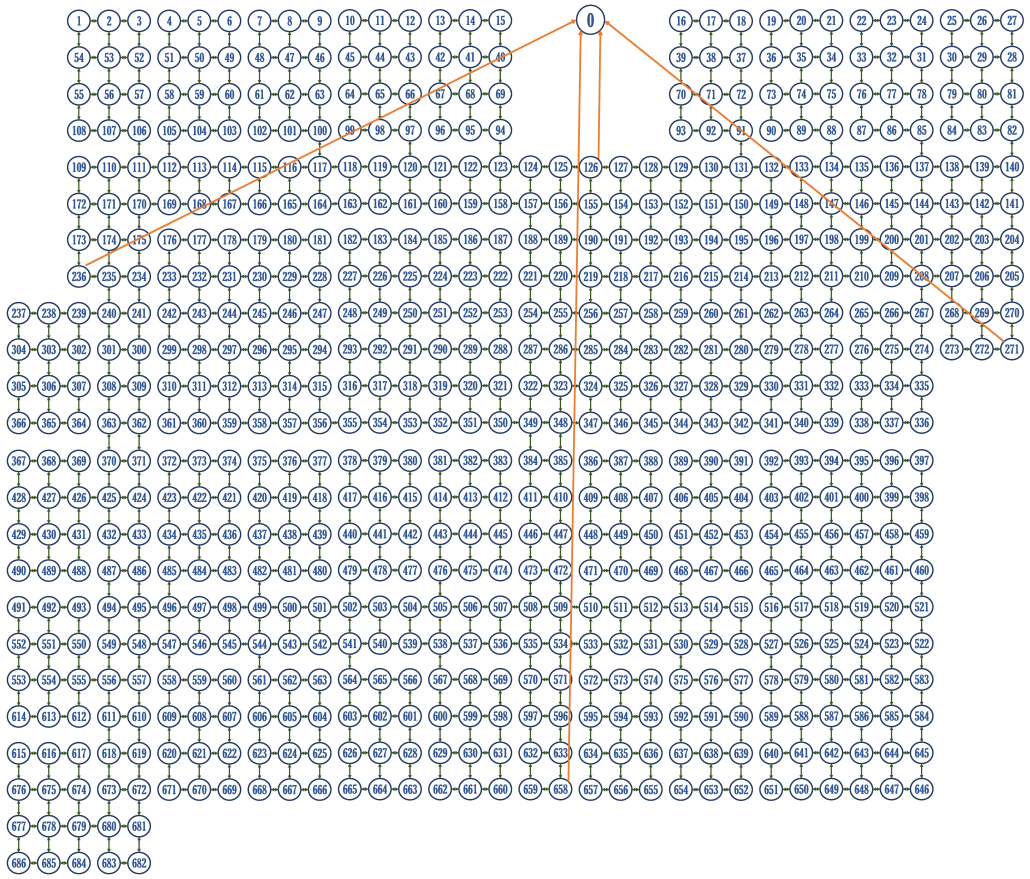


Figure 9. Network associated with the plan of Figure 8.

Table 3. Evacuation and computation time for time-decomposed scenarios: *a*) 3×3 **cells (time slots of 2.5 seconds);** *b*) 1.5×1.5 **cells (time slots of 1.25 seconds).**

$\tau(a)$	evacuees (a)	CPU Time (a)	$\tau(b)$	evacuees (b)	CPU Time (b)	$\tau(b)$	evacuees (b)	CPU Time (b)
1	12	0.48 sec	1	6	2.43 sec	41	205	1.89 sec
2	24	0.56 sec	2	12	3.11 sec	42	208	1.88 sec
3	36	0.45 sec	3	18	2.45 sec	43	210	1.89 sec
4	48	0.54 sec	4	24	2.42 sec	44	212	1.89 sec
5	60	0.56 sec	5	30	2.31 sec	45	213	1.83 sec
6	72	0.50 sec	6	36	2.39 sec	46	215	1.85 sec
7	84	0.51 sec	7	42	2.32 sec	47	216	1.86 sec
8	96	0.52 sec	8	48	2.53 sec	48	218	1.82 sec
9	108	0.49 sec	9	54	2.45 sec	49	219	1.89 sec
10	120	0.51 sec	10	60	2.54 sec	50	221	1.84 sec
11	132	0.48 sec	11	66	2.39 sec	51	222	1.90 sec
12	144	0.55 sec	12	72	2.42 sec	52	224	1.84 sec
13	156	0.50 sec	13	78	2.30 sec	53	225	1.90 sec
14	168	0.58 sec	14	84	2.48 sec	54	227	1.85 sec
15	180	0.56 sec	15	90	2.48 sec	55	228	1.92 sec
16	192	0.51 sec	16	96	2.89 sec	56	230	1.93 sec
17	204	0.53 sec	17	102	2.24 sec	57	231	1.84 sec
18	211	0.52 sec	18	108	1.97 sec	58	233	1.85 sec
19	217	0.41 sec	19	114	2.05 sec	59	234	1.82 sec
20	223	0.43 sec	20	120	1.90 sec	60	236	1.87 sec
21	229	0.43 sec	21	126	1.98 sec	61	237	1.83 sec
22	235	0.52 sec	22	132	1.95 sec	62	239	1.85 sec
23	241	0.43 sec	23	138	2.04 sec	63	240	1.87 sec
24	246	0.50 sec	24	144	1.99 sec	64	242	1.91 sec
25	249	0.39 sec	25	150	1.87 sec	65	243	1.95 sec
26	252	0.55 sec	26	156	1.86 sec	66	245	1.89 sec
27	255	0.50 sec	27	162	187 sec	67	246	1.81 sec
28	258	0.51 sec	28	166	1.93 sec	68	248	1.89 sec
29	261	0.53 sec	29	169	1.93 sec	69	249	1.85 sec
30	264	0.50 sec	30	172	1.85 sec	70	251	1.95 sec
			31	175	1.87 sec	71	252	1.84 sec
			32	178	1.87 sec	72	254	1.85 sec
			33	181	1.89 sec	73	255	1.92 sec
			34	184	1.86 sec	74	257	1.90 sec
			35	187	1.90 sec	75	258	1.81 sec
			36	190	1.96 sec	76	260	1.90 sec
			37	193	1.83 sec	77	261	1.94 sec
			38	196	1.89 sec	78	263	1.81 sec
			39	199	1.82 sec	79	264	1.98 sec
			40	202	1.96 sec			

1. *Centralized with High Resolution (Centralized-HR)*: the critical situation is handled by a continuous simulation of the algorithm, (on a single controller) and physical space is divided into 1.5×1.5 cells.
2. *Centralized with Low Resolution (Centralized-LR)*: the critical situation is handled by a continuous simulation of the algorithm, (on a single controller) and physical space is divided into 3×3 cells. Therefore, again all tasks are routed to a central controller.
3. *Collaborative with High Resolution (Collaborative-HR)*: the situation is handled by a time-decomposed simulation of the algorithm, (on collaborative controllers) and physical space is divided into 1.5×1.5 cells. This means that the two available controllers are intermittently chosen as the destination of routed tasks.
4. *Collaborative with Low Resolution (Collaborative-LR)*: the emergency situation is handled by a time-decomposed simulation of the algorithm, (in a collaborative way) and physical space is divided into 3×3 cells. Thus, one of the controllers handles the situation for *odd* and the other for *even* time slots.

Answers to RQ3: Total Delay Assessment using Queuing Networks Parameterization

In order to realize the software architectures resulting from algorithm simulations, we exploit the QN of Fig. 3 that we have previously introduced, with the four different sets of input parameters needed to model the software architectures resulting from algorithm simulations.

Sense tasks (by CCTVs) are generated at a certain rate (i.e. every 2.5 seconds for high resolution and 1.25 seconds for low resolution networks). These rates are the monitoring frequencies, and is the time taken for an individual to cross a single cell in our crowd monitoring algorithm. Such time intervals represent a key-value, due to their impact on the overall evacuation delay.

Exponential distributions are used to define CPU times. Table 4 reports the means of such distributions for our case study, which have been estimated in several ways. Our focus is on evacuation, i.e. *CriticalPlan-HR* and *CriticalPlan-LR*, which have been estimated by formulating the evacuation handling problem within CPLEX. Other parameters are set as follows:

- Service time distribution means for sensors, networks and actuators, have been obtained by modelling the IoT system for the Alan Turing building with CAPS, our simulation framework (Muccini and Sharaf 2017). CPU times for sensors, actuators and networks, have been calculated in terms of transmission and propagation delays (*td* and *pd*, respectively).
- Service time distribution means for controllers refer to SMAPEA task types. *Sense* tasks have zero CPU time since they do not introduce additional computation for controllers, hence they just need to be transformed into *Monitor* tasks.
- As shown in Table 4, *Monitor* and *Execute* tasks are equal and have the same order of magnitude of *Analyze*. To avoid further complexity, we ignore formulating optimization models for such task types, by setting arbitrary values as follows: we assume that aggregating raw data (i.e. *Monitor*) and building a list of atomic actions to execute (i.e. *Execute*) are less demanding than interpreting monitored data (i.e. *Analyze*).

Table 4. SMAPEA Task Types and CPU Times for case Study

SAMPEA-QN Layer	Service Center	Task Type		Mean CPU time (exp)		Notes
		ID	Name	Centralized	Collaborative	
Perception	CCTVs	1	CctvSense	0.01386		*By CAPS (td).*
Network	PL2IL	2	CctvSense	0.023480633		*By CAPS (td+pd).*
P&S	Controllers	3	Sense	0		*Sense just becomes xMonitor*
		4	CriticalMonitor	0.0045067	0.0045067	*Arbitrarily set.*
		5	CriticalAnalyze	0.00676	0.005735	*By CPLEX.*
		6	**CriticalPlan-HR**	110.1791139	2.0164557	*By CPLEX*
		7	**CriticalPlan-LR**	1.1668182	0.5016667	*By CPLEX*
		8	CriticalExecute	0.0045067	0.0045067	*Arbitrarily set.*
Network	IL2AL	9	DashboardActuate	0.013619641		*By CAPS (td+pd).*
		10	AlarmActuate	1.013619641		
		11	EvacuationSignsActuate	2.013619641		
Application	Dashboards	12	DashboardActuate	0.000921667		*By CAPS (td).*
	Alarms	13	AlarmActuate	0.000921667		
	EvacuationSigns	14	EvacuationSignsActuate	0.000921667		

Simulation. We assess the total delay corresponding to each IoT architectural pattern design based on the flow algorithm, for the case study. The response time (delay) that is analyzed is the mean time spent from starting the sampling to the time that actuation ends.

Table 5 reports, for each scenario, the overall system response time (in seconds) in the second column and the architectural design decision in the third one (useful to answer RQ4).

Table 5. Experimental results.

Pattern	System response time (s)	Architectural design decision
Centralized with HR	*System saturation*	Unfeasible (real-time requirement)
Centralized with LR	*1.5085*	Feasible
Collaborative with HR	*26.5597*	Unfeasible (real-time requirement)
Collaborative with LR	*0.5864*	Unfeasible (non-optimal)

Answers to RQ4: Architectural Design Decision. Experimental results show that, in LR, the Collaborative pattern minimizes system response time. However, this pattern does not satisfy the precondition that minimizes operational delay, i.e. optimal evacuation of people from the building. Thus, one can argue that a Centralized pattern should be imposed when working in a critical mode. The drawback is that, managing critical cases with Centralized increases system response time in critical mode by more than 200% with respect to Collaborative. Therefore, the solution can be using HR network. However, HR does not allow the system to fulfill a real-time requirement, due to two factors: *i)* working in HR requires much more CPU time; *ii)* the sampling rate doubles when working in HR. Both factors contribute to a significant performance worsening which might lead to system saturation (as for Centralized-HR).

As a result of the considerations above, *only one pattern could be adopted, i.e. Centralized-LR*.

It is worth noticing that, in order to face the sampling rate for HR (i.e. 1.25), while satisfying the precondition that minimizes operational delay, the CPU time of the controller in Centralized pattern should have the same order of magnitude of the controllers in Collaborative-LR. For example, with a CPU time of 0.5016667 (i.e. the same as Collaborative-LR), Centralized-HR would show a system response time of 0.6535 seconds (i.e. 11.5% Collaborative-LR). As a second example, with a CPU time of 2.0164557 (i.e. the same as Collaborative-HR), Centralized-HR would experience continuous saturation that might lead to a system response time in the order of hours.

CONCLUSION

This work uses the Queuing Network concept in order to model the IoT architectural patterns for emergency evacuation, and assess the patterns' corresponding delays. The architecture has a core computational component in the form of network flow, which supports the design decision by providing the model with expected operational and computational delays. Preliminary evaluations using data from a real case, and an *ad-hoc* IoT infrastructure showed the suitability of a centralized software architecture based on a low resolution division of the building surface.

REFERENCES

Arbib, C., Moghaddam, M. T., and Muccini, H. (2019). "IoT Flows: A Network Flow Model Application to Building Evacuation". In: *M. Gaudioso, M. Dell'Amico and G. Stecca (Eds.) A view of operations research applications in Italy.* Springer.

Arbib, C., Muccini, H., and Moghaddam, M. T. (2018). "Applying a network flow model to quick and safe evacuation of people from a building: a real case". In: *Proceedings of the GEOSAFE Workshop on Robust Solutions for Fire Fighting, RSFF 2018, L'Aquila, Italy, July 19-20, 2018.* Pp. 50–61.

El Kafhali, S. and Salah, K. (2018). "Performance Modeling and Analysis of IoT-enabled Healthcare Monitoring Systems". In: *IET Networks*.

Huang, J., Li, S., Chen, Y., and Chen, J. (2018). "Performance modelling and analysis for IoT services". In: *International Journal of Web and Grid Services* 14, p. 146.

Lazowska, E. D., Zahorjan, J., Graham, G. S., and Sevcik, K. C. (1984). *Quantitative system performance - computer system analysis using queueing network models*. Prentice Hall.

Muccini, H., Arbib, C., Davidsson, P., and Tourchi Moghaddam, M. (2019). "An IoT Software Architecture for an Evacuable Building Architecture". In: *Proceedings of the 52nd Hawaii International Conference on System Sciences*, pp. 678–687.

Muccini, H. and Moghaddam, M. T. (2018). "IoT Architectural Styles". In: *European Conference on Software Architecture*. Springer, pp. 68–85.

Muccini, H. and Sharaf, M. (2017). "Caps: Architecture description of situational aware cyber physical systems". In: *Software Architecture (ICSA), 2017 IEEE International Conference on*. IEEE, pp. 211–220.

Muccini, H., Spalazzese, R., Moghaddam, M. T., and Sharaf, M. (2018). "Self-adaptive IoT architectures: an emergency handling case study". In: *Proceedings of the 12th European Conference on Software Architecture: Companion Proceedings*. ACM, p. 19.

Track 6.

Geospatial Technologies and Geographic Information Science for Crisis Management (GIS)

Chairs

João Porto de Albuquerque, *University of Warwich, UK*

Alexander Zipf, *University of Heidelberg, Germany*

Flávio E. A. Horita, *Federal University of ABC, Brasil*

Exploring multiplexing tools for co-visualization in crisis units

Pierkot Christelle
Univ. Paul-Valéry Montpellier 3, IRD, UMR GRED 220, F-34000 Montpellier, France
christelle.pierkot@univ-montp3.fr

Christophe Sidonie
Univ. Paris-Est, LASTIG GEOVIS, IGN, ENSG, F-94160 Saint-Mande, France
Sidonie.Christophe@ign.fr

Girres Jean-François
Univ. Paul-Valéry Montpellier 3, IRD, UMR GRED 220, F-34000 Montpellier, France
jean-francois.girres@univ-montp3.fr

ABSTRACT

Natural hazards can generate damages in large inhabited areas in a very short time period. Crisis managers must plan interventions very quickly to facilitate the arrival of the first emergency. In a crisis unit, experts visualize heterogeneous visual representations of spatio-temporal information, in order to facilitate decision-making, based on various types of screens, i.e. laptops, tablets, or wall screens. Visualizing all this information at the same time on the same interface would lead to cognitive overload. In this paper, we assume that it could be of interest to provide innovative co-visualization models and tools, to bring hazard, geospatial and climate information together, in a shared interface. We propose to explore spatial and temporal multiplexing tools within a dedicated geovisualization environment, in order to help expert decision-making. The proposition is implemented with the case study of a tsunami event in the Caribbean sea.

Keywords

geovisualization, multiplexing tools, crisis management.

INTRODUCTION

Natural hazard management remains a major issue for populations and authorities. It relies on the capacities and the possibilities that scientific and operational have to simulate, predict and prevent natural phenomena in order to protect the impacted inhabitants and infrastructures. Decision-making processes can be complex and mostly depend on quickly transmitted information, based on massive raw data coming from sensors and geophysical models: this information is then often graphically represented as graphics and maps, enabling visualizations of the territories affected by an event, the dynamic evolution of this event in space and time, and its various possible impacts. In a crisis unit, the goals of the experts are to lead emergency and people security: they rely on information, coming from various sources, sensors, and other emergency centers, displayed on different screens, i.e. laptops, tablets or wall screens, variably arranged in the room, to take the better decisions (Cf. Figure 1).

Figure 1: Inside a crisis management unit (Photo Credit PREDICT Services[1])

For instance, when facing a tsunami event, emergency information is transmitted in a raw text format and are combined with pre-computed event forecast models to extract and derive the expected spatial extension and the related potential impacts. Figure 2 presents the example of a raw alert message in text from the Pacific Tsunami Warning Center (PTWC) (2-a) and one of a possible derived cartographic representation (2-b). At the same time, other information need to be visualized, in order to assess the dangerousness of an event, its extension and dynamics, for instance: meteorological information, i.e. wind, local and worldwide pluviometry at the time and the trends for the past two weeks, seismologic activity, etc.

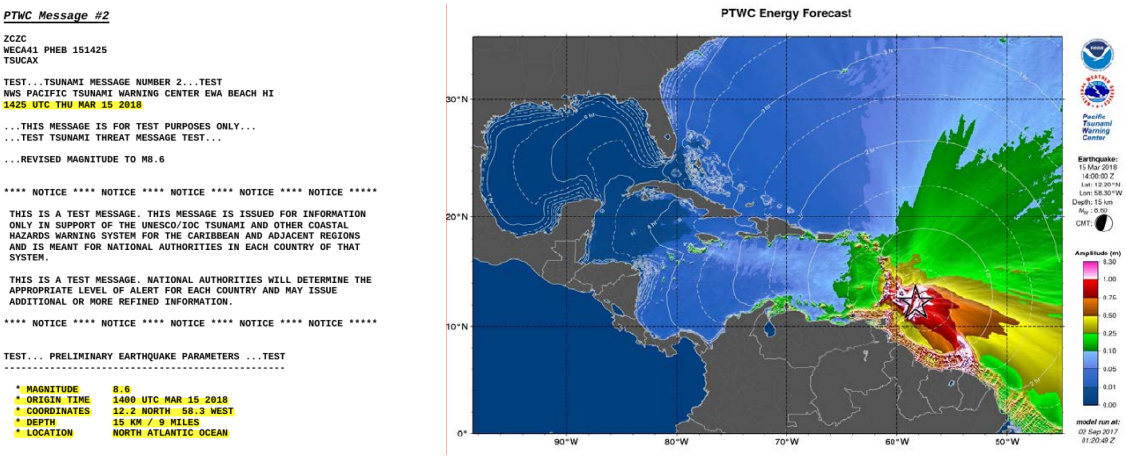


Figure 2: a) PTWC raw alert message and b) Maximum amplitude map for the Caribbean and Adjacent Regions (PTWC, 2018)

This research initially emerged during various visits of crisis units, where wall screens are used to represent heterogeneous spatio-temporal information useful for crisis management. During these visits, we observed that a lot of data are displayed on wall screens at the same time, in 2D or 3D, whatever spatio-temporal extents and scales. However, we have noticed several functional limits for the co-visualization and the navigation of information displayed on wall screens.

First of all, the representations displayed on a wall screen were independent one to each other, which did not allow an efficient cross-over between representations, and could generate too many unnecessary interactions with the representations. Independence and hermeticism of the representations (often provided in raw format by web services) prevented to display this information on a unique representation. Furthermore, a temporal interdependence exists between representations, which is fundamental in a crisis management context with strong temporal constraints. For example, synchronization between tsunami arrival, hourly weather conditions, and evacuation times to a safe place can not be considered separately. Moreover, the possibility of anticipating by taking advantages of the temporal relations between representations proves to be invaluable for crisis experts.

In the context of a catastrophic event, decision makers and experts in a crisis unit have to face significant temporal constraints, while acting on potentially vast areas. Wall displays offer a solution to co-visualize the various representations useful for decision-making, but at the same time, the difficulty of combining these

[1] http://www.predictservices.com

representations can amplify these constraints. It therefore seems necessary to identify geovisualization tools and methods to manage co-visualization of heterogeneous representations in crisis units. In this context, we assume that advances in Geographic Information Sciences could benefit crisis managers to better navigate, combine and synchronize information displayed on wall screen in crisis units.

Geographic Information (GI) sciences have facilitated the development of geovisualization design and use, enabling experts to conduct more elaborate actions for risk prevention and crisis management (Van Oosterom et al., 2005; Konecny et al., 2010). While *mapping* is a graphic representation of geographical spaces and phenomena more used to communicate and mediate, *geovisualization* regards the way data may be visualized based on data interaction, to lead to *visual analytics* capacities, i.e. to infer spatio-temporal knowledge from data exploration (Keim et al. 2008). Geovisualization issues mainly concern the handling of heterogeneous spatio-temporal data visualization and the design of suitable graphic choices when representing uncertainties and spatio-temporal evolutions and their adaptation to the potential final users (experts, public authorities, populations). Nevertheless, the development of geovisualization tools for crisis management remains complex because of the emergency context and time pressure, of the increasing amount of available data, and of the risk of a cognitive overload instead of the expected cognitive support. In crisis management units, in the usual way, in order to avoid these problems, information is split on several screens to facilitate their access and reading. Based on these observations, we have been wondering if another organization of graphic interfaces could be useful and relevant in order to support sophisticated cognitive processes of knowledge inference and decision-making about crisis management, coming from a facilitating co-visualization of heterogeneous spatio-temporal data. *Co-visualization* refers to the methods and tools to bring representations together, in a shared interface *(*Hoarau and Christophe, 2017). We assume that this visual data integration will better support visual analytics and could help in the earlier steps of decision-making in a crisis management context.

In this paper, we propose to initiate this research by a proper design experiment step to explore the potentialities of spatial and temporal multiplexing tools, associated with a dedicated geodata visualization environment. Our long-term purpose is to provide a suitable visual support for knowledge inference and decision-making on crisis management in the case of natural disasters. In the first step of this long-term research, we focus on the issues related to the proposition of interface tools design, which are our first contribution to solve the on-going research problem: user studies have not been conducted in this first step, because a proper design needs to first approach issues of how to visually integrate data and representations. We present the advances in geovisualization, and especially in co-visualization of data and graphic representations, and the visual possibilities enhanced by multiplexing tools, in our crisis management context. Afterwards, we propose a generic model to better co-visualize the geospatial and thematic data, based on various points of view that could be displayed in a same graphic interface. As an applicative use case, we consider a tsunami event in the Caribbean sea, with a focus on the Martinique island, with the help of an existing detailed scenario proposed as part of the crisis exercise *CARIBE WAVE 18* (PTWC, 2018). We detail the scenario and the dataset used to simulate the event. Finally, we demonstrate the implementation of multiplexing tools to handle heterogeneous data to better co-visualize information on a tsunami event.

ADVANCES IN GEO-VISUALIZATION & CO-VISUALIZATION FOR CRISIS MANAGEMENT

Geovisualization refers to the "theory, methods and tools for visual exploration, analysis, synthesis, and presentation of geospatial data" (MacEachren & Kraak, 2001). As an interdisciplinary domain between GI sciences, geography, information visualization, image processing and computer graphics, geovisualization provides conceptual approaches, methods and tools to interact with geospatial data. Through this capacity to let the users explore the data and their representations, geovisualization tools aim at inferring knowledge and supporting visual reasoning (Yi et al. 2007). Nowadays co-visualization may benefit from the advances in the Human-Computer Interaction (HCI) scientific domain, providing spatial and temporal multiplexing tools to manipulate data 'together'. In order to improve the usability of co-visualization tools to manage data in space and time, the main leads undergoing research are the following ones: the improvement of the perception of the dynamics of a phenomenon and the design of smooth navigation between data and representations.

Spatio-temporal geovisualization

Geovisualization has widely considered issues related to the representation and the interaction with spatio-temporal data (Andrienko & Andrienko 2005, Andrienko et al. 2008, amongst others). The first main approach is to animate the spatial or/and temporal dynamics at stake, in a continuous or pseudo-continuous manner (Andrienko et al., 2008; Keim et al., 2008). Many applications have been experimented, the water level rising

simulation (Marcy et al., 2011; Nicholls et Cazenave, 2010; Yang et al., 2014), tsunami and marine submersion prevention (Allen et al., 2010), the modeling and visualization of currents and tides (Mengguo et al., 2000), the monitoring of sandbanks trajectories (Gierlinger et al., 2015) and seabeds (Tateosian et al., 2014), or the real-time representation of maritime traffic (Etienne et al. 2012, Marine Traffic[2]). These spatio-temporal animations are more and more used, thanks to the increasing rendering capacities of computers, in order to serve fluid and continuous animated visualizations. Nevertheless, even if animations are very useful to improve the global perception of a spatio-temporal phenomenon and its general patterns, such as demonstrated in a user study of geovisualization and assessment of a flood crisis (Leskens et al., 2015), it is mostly difficult to detect changes and to monitor a specific aspect of the phenomenon (Rensink et al., 1997). These previous work show that a dynamic visualization is a better way to understand, but also suggest that several points of view are required to observe and analyze a spatio-temporal phenomenon.

Co-visualization techniques from Geographic Information (GI) Sciences

Co-visualizing heterogeneous data raises issues on how it is possible to visualize data together, sharing the same interface side by side, overlapping each other, or being hybridized or merged in one new image. Map design researches have addressed for instance the design problem of visually mergin an ortho-image background with an abstract topographic map (Hoarau, 2012; Raposo and Brewer, 2013). While merging data, legibility issues appear, implying issues in graphic semiotics and its related visual variables, initially described by Bertin (1983), extended, revisited and experimented, by MacEachren (1995), Boukhelifa et al. (2015), Carpendale (2003), Slocum et al. (2009), Perin et al. (2014), amongst others. Issues on colors and color contrasts (Christophe, 2011; Harrower and Brewer, 2003; Patterson and Kelso, 2004; Patterson and Jenny 2013; Thyng et al. 2016 amongst others) may be also addressed in this co-visualization context, such as rendering techniques to variously blend geographical layers (Porter and Duff, 1984; Hoarau and Christophe, 2016; Lobo et al. 2015). The unique use of the transparency to blend data may cause visual cluttered information not legible and not usable: blending data require specific techniques mostly to handle contrasts (Hoarau et al., 2013; Murphy 2015). Therefore, the design of continuum of data and graphic representations has been explored as 'a series of pictures, iteratively reduced in representation from its referent' (Medley and Haddad, 2011). In GI sciences, the design of cartographic continuum aims for instance at navigating smoothly, between a map and orthoimagery according to the parametrization and interpolation of colors and textures to enhance photorealism (Hoarau & Christophe 2017) or smoothly between various representation scales to manage visual attention (Dumont et al., 2017). Managing progressive transitions between levels of abstraction allows navigating between different levels of abstraction in a same visualization, according to the distance from the image center or the saliency of rendered objects (Semmo et al., 2012), or according to the scene depth (Semmo and Döllner, 2014). Another example consists in generating masks according to relevant geographical objects and scene depth, in order to highlight specific objects as soon as the users perceive them (Trapp et al., 2011).

Multiplexing techniques

Navigating in large information spaces using zoomable user interfaces is a research question that has received a lot of attention in the Human-Computer Interaction (HCI) community, based on three main interface schemes: pan & zoom (Wijk and Nuij, 2003), focus+context and overview+detail (see Cockburn et al., 2009 for a comprehensive survey). The implementation of navigation techniques from HCI based on these schemes leads to a wide range of tools supporting multiplexing (Bottger et al. 2008; Brosz et al., 2013; Jakobsen et al. 2013; Reilly and Inkpen, 2004), i.e. tools conveying multiple information at the same time: such as magnifiers, lenses, swipes, or enslaved views (Appert et al. 2010; Pietriga et al. 2010; Pindat et al., 2012; Karnik et al., 2009; Lobo et al., 2015), evaluated in (Lobo et al., 2015). These spatial multiplexing tools may be divided into:

- Juxtaposition methods, i.e. two types of data are displayed in the same environment, but one besides the other, or one up the other: multiviews, overview and detail, split screen, portal.
- Superimposition methods, i.e. two types of data are overlaid, some of them may be hidden and visible with the help of an interface tool: mash-up, translucent overlay, swipe, dragmap (Ware & Lewis, 1995), lenses, as Smart Lenses (Thiede et al., 2008), Jelly Lens (Pindat et al., 2012), Detail Lenses (Karnick et al. 2010) amongst others (see Tominski et al., 2014 for a wider survey about lenses).

Co-visualization of heterogeneous data based on multiplexing techniques

[2] https://www.marinetraffic.com/en/ais/

Because of the amount of heterogeneous data that have to be handled, visualized and cognitively processed, together, in the same time, in a crisis unit, we may take advantages of the parallel advances in geovisualization and in HCI: they provide a strong state of the art to go further in the co-visualization of heterogeneous spatio-temporal data, based on multiplexing techniques for crisis management. A combination of juxtaposition methods, i.e. multiviews, overview and detail, and of superimposition methods, such as lenses, could allow to render the region of interest or any subregions, according to these constraints:

- With different input information: topographic, thematic regarding the event, climate, textual data, sociodemographic;
- With various points of view on the event: representation of hazard, potential issues, and elements at risk;
- At different time steps: before, during of after the event;
- At different spatial scales: international, regional, local, urban;
- For any natural event: tsunami, flood, water level raising, etc.;
- For distinct objectives: monitoring, evacuation, etc.

Taking into account these multi-dimensional constraints for the co-visualization of information in a crisis unit supposes the development of a generic model for the management of heterogeneous graphic representations.

GENERIC MODEL TO VISUALIZE INFORMATION IN VARIOUS WAY

To improve the co-visualization of heterogeneous data in a crisis context, we argue that the intended information to represent and the way it is displayed on various screens (wall screens, laptops, tablets, etc.) must be preliminarily identified. For example, in a crisis unit, at the beginning of an event, some information have to be visualized onto a wall screen, such as the source of the hazard, the impacted areas, alert messages, or climate data. This information must be displayed, at different scales (according to the spatial extension of the event) to make it possible for the operator to view the representations at different levels of detail. This raises both:

- User Interface (UI) issues: How to efficiently organize information displayed on the screen? Which tools can be used to better represent information?
- Geospatial issues: What kind of spatio-temporal (ST) relationships exist between representations? How to mash-up heterogeneous datasets with different scales and styles ?

A generic metamodel for interface handling

We propose a generic model to describe entities used in a particular hazard context (e.g. tsunami or flood). In this model, we need to consider interface issues, such as co-visualization of heterogeneous datasets. At the highest level, we have to manage the three concepts of interfaces, frames and scenes and their relationships, as modeled in Figure 3.

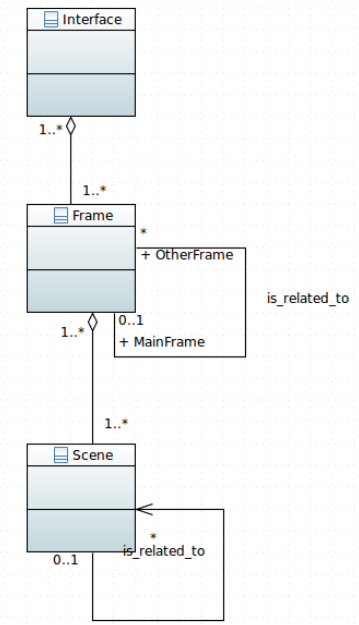


Figure 3: Generic metamodel of interfaces relationships interaction in a co-visualization framework (UML diagram)

An *interface* allows the users to interact with the information within a dedicated support (wall screens, tablets, etc.); a *frame* is a 2D visualization space inside the interface where contextual information is displayed; and a *scene* is a static or dynamic representation at one scale and for one particular time (before, during of after the event). In the context of crisis management, an interface must allow the experts to:

- Co-visualize heterogeneous, cartographic and thematic data (weather, alert message, topographic data, etc.);
- Hide / show / combine relevant information for the user;
- Put forward a frame or a scene that is considered as the main one, at a certain time t;
- Interact with data through multiplexing tools.

Interfaces are composed by frames and interaction components. Each frame constitutes a 2D visualization space in which different scenes are represented. Frames can be represented by windows, popup, widget, or any component of a GUI which allow displaying cartographic or thematic information. Frames can be related to each other. In particular, one frame is dedicated to be the main for displaying the most relevant scene for the operator at one time. This main frame can have some links with the others (e.g. zoom of a particular place, thematic information for a particular placemark, etc.). Spatial and temporal multiplexing tools can be used at this level, such as juxtaposition of several frames (multiview, split/merge, etc.), superimposition (dragmag, mash-up, etc.), or temporal synchronization of frames. In the frames, we have to represent one or more *scenes*, corresponding to a particular *spatial scale* (region, local, urban), at a particular time (synchronized with the event time). Scenes can be related to each other.

A model to manage scenes

At the scene level, we have to manage the graphic representation, the different link between them and the associated dataset. The Figure 4 presents a conceptual model (UML formalism) to describe the interaction and the relationships between entities at this level.

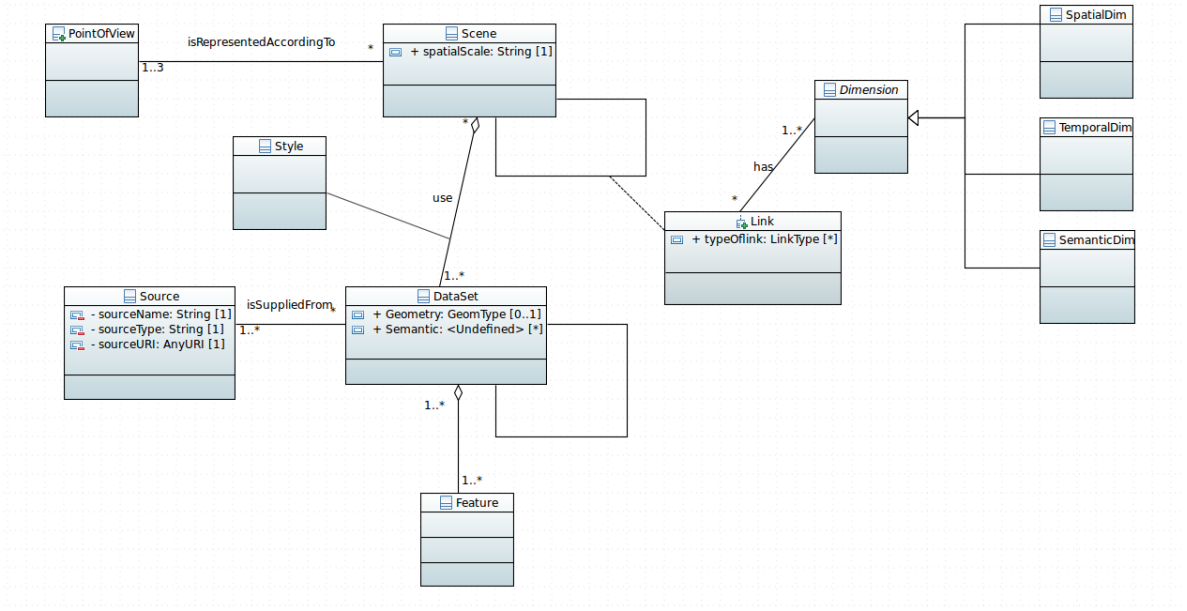


Figure 4: Scene level model (UML class diagram)

A *scene* is represented according to a *Point of view*. In our context, we consider diverse points of view: *Hazard, Potential Issue and Risk*. The *hazard* refers to the direct or indirect consequences of a catastrophic natural phenomenon. It can be amplified with other phenomenon, such as additional and cumulative rainfall for instance. *Potential Issue* contains information about people or infrastructures potentially exposed to the phenomena. *Risk* is the intersection between hazard and potential issues (e.g. submerged roads, destroyed buildings, etc.). For one scene, several *spatial or thematic datasets* are needed to graphically represent the information. A *style* depending on the scale of representation and the dataset used to display the information is applied. Datasets are supplied from different *sources* (databases, geoportal, etc.). Finally, spatial, temporal and semantic links can exist between scenes: for example, alert messages and estimated intensity of the hazard can be synchronized. These relationships will guide the use of multiplexing tools, to better combine the information to be disseminated. For instance, at the *hazard* point of view, data about the prediction of the impacted area can be easily found, and at the *potential issue* point of view, data on the impacted population in the same area are available. Lenses would potentially be helpful to see a specific aspect of the phenomenon (scale, data or view change) or of the impacts (affected population or infrastructures) or of the complementary thematic data (rainfall evolution, etc.) and to show how to reach quickly some refuge sites.

TSUNAMI CRISIS SCENARIO AND UNDERLYING DATASET

The crisis scenario is based on the Barbados earthquake scenario from the *CARIBE WAVE 18* exercise (PTWC, 2018). It relays on a rupture of a fault segment along the Caribbean coast of Barbados, occurred at 14:00 UTC, causing an earthquake with an 8.6 magnitude. The epicenter is located at the coordinates Long : 58.30°W, Lat : 12.20°N. With this scenario, the southern segment of the Lesser Antilles ruptures to create a tsunami. Expected impacts for this event are determined from pre-computed tsunami forecast models. For instance, Figure 5 shows tsunami travel time and water heights off the coast. Tsunami forecast models indicate a significant tsunami along several coasts in the Caribbean Sea. Threat messages and enhanced graphical products will be disseminated to officially designated agencies. The initial alert is disseminated at 14:05 UTC.

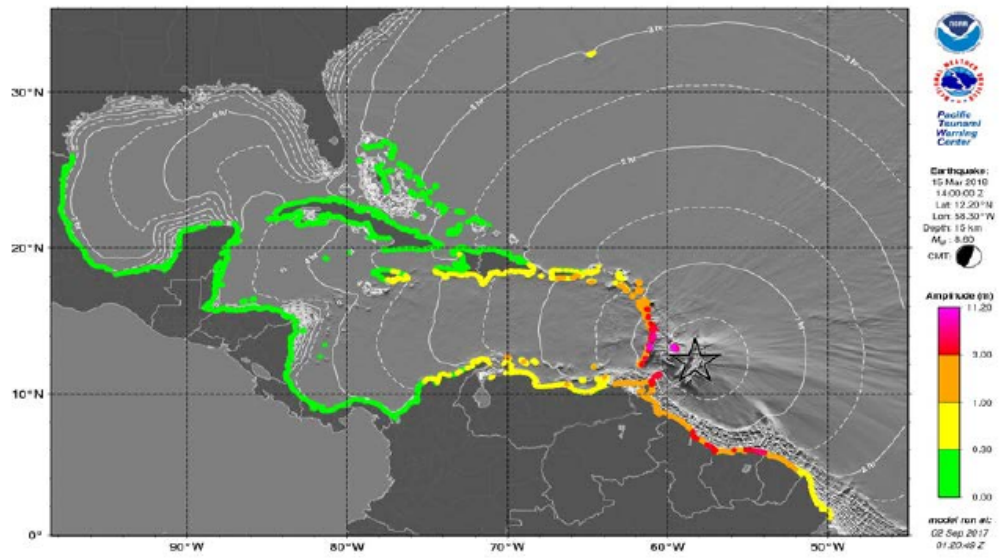


Figure 5 : Coastal tsunami amplitude map for the Caribbean and adjacent regions (PTWC, 2018)

The first tsunami threat message issued by PTWC is based on the earthquake magnitude (8.3 reevaluate in the second message) and the tsunami travel times (Figure 5). The other messages are based on tsunami wave forecasts that indicate the levels of threat that have been forecast and to which countries or places they apply. The messages cover a period of time between 5 minutes and 7-hours from earthquake origin time. The end of the event is scheduled at 18h00 UTC (PTWC, 2018). Based on this scenario, experts, in a crisis unit, and during the crisis period, have to manage emergency and people security for the french islands of Caribbean region, and in particular the Martinique island.

PTWC Message #1

```
ZCZC
WECA41 PHEB 151405
TSUCAX

.TSUNAMI MESSAGE NUMBER 1.
NWS PACIFIC TSUNAMI WARNING CENTER EWA BEACH HI
1405 UTC THU MAR 15 2018

. PRELIMINARY EARTHQUAKE PARAMETERS .
-------------------------------------------

* MAGNITUDE      8.3
* ORIGIN TIME    1400 UTC MAR 15 2018
* COORDINATES    12.2 NORTH  58.3 WEST
* DEPTH          15 KM / 9 MILES
* LOCATION       NORTH ATLANTIC OCEAN

. EVALUATION .
-------------------------

* THIS IS A TEST MESSAGE. AN EARTHQUAKE WITH A PRELIMINARY
  MAGNITUDE OF 8.3 OCCURRED IN THE NORTH ATLANTIC OCEAN AT
  1400 UTC ON THURSDAY MARCH 15 2018.

* THIS IS A TEST MESSAGE. BASED ON THE PRELIMINARY EARTHQUAKE
  PARAMETERS... WIDESPREAD HAZARDOUS TSUNAMI WAVES ARE
  POSSIBLE.
```

```
. ESTIMATED TIMES OF ARRIVAL .
---------------------------------------

* THIS IS A TEST MESSAGE. ESTIMATED TIMES OF ARRIVAL -ETA- OF
  THE INITIAL TSUNAMI WAVE FOR PLACES WITHIN THE REGION
  IDENTIFIED WITH A POTENTIAL TSUNAMI THREAT. ACTUAL ARRIVAL
  TIMES MAY DIFFER AND THE INITIAL WAVE MAY NOT BE THE
  LARGEST. A TSUNAMI IS A SERIES OF WAVES AND THE TIME BETWEEN
  WAVES CAN BE FIVE MINUTES TO ONE HOUR.

LOCATION          REGION              COORDINATES     ETA(UTC)
-------------------------------------------------------------
BRIDGETOWN        BARBADOS          13.1N  59.6W    1428 03/15
KINGSTOWN         SAINT VINCENT     13.1N  61.2W    1448 03/15
CASTRIES          SAINT LUCIA       14.0N  61.0W    1452 03/15
PIRATES BAY       TRINIDAD TOBAGO   11.3N  60.6W    1459 03/15
FORT DE FRANCE    MARTINIQUE        14.6N  61.1W    1500 03/15
ROSEAU            DOMINICA          15.3N  61.4W    1500 03/15
SAINT GEORGES     GRENADA           12.0N  61.8W    1506 03/15
BASSE TERRE       GUADELOUPE        16.0N  61.7W    1509 03/15
PLYMOUTH          MONTSERRAT        16.7N  62.2W    1517 03/15
```

Figure 6 : PTWC Threat Message N°1: On the left, information are provided about the earthquake, on the right each line represents the estimate times of arrival of the Tsunami wave for different towns.

Table 1 describes our proposition of required information and multiplexing tools, according to three relevant spatial scales, regional, local and urban, and their related associated tasks: alertness, risks assessment and evacuation. For each spatial scale, several datasets are necessary to achieve these tasks: the row "Information to display" gives the relevant required information for each spatial scale, for all the points of view (Hazard, Potential Issues and Risk):

Spatial Scale	Regional ◄——► Local ◄——► Urban		
Associated task	Alertness	Risk assesment	Evacuation
Information to display	Base Map + Épicenter information, Tsunami Travel Time, PTWC Messages,	Base Map + **Hazard**: submerged area + coastline water hight **Potentiel Issues**: Buildings, roads and population **Risk**: Refuge sites, area to evacuate **Weather**: Rainfall	Base Map + **Hazard**: Submerged area **Potential Issues**: Buildings, roads, population and boats **Risk**: Refuge sites, population and boats to evacuate
Multiplexing tools associated	**Spatial multiplexing**: *Swipe*: wave progression **Temporal multiplexing**: TTT *animation*.	**Spatial multiplexing** *Mash-up:* weather and topographic information **Temporal multiplexing** Rainfall *animation*	**Spatial multiplexing**: *Split-Merge*: Risks information *Lens*: ≠ Point of view

Table 1 : Datasets and multiplexing tools used according to the three spatial scale and their related tasks.

- At the regional spatial scale, the task is “alertness”: the experts need to have a global vision of the event and its probable consequences. A base map of the whole region with the location of the epicenter, and the PTWC alert message are needed. Additionally, the Tsunami Travel Time (TTT) and the earthquake information must be displayed upon request. Data used at this level are extracted from the PTWC alert message.
- At the local spatial scale, the task is “risk assessment”: the experts have to see information for the entire island to decide where to dispatch the rescues first. Thus, they need information about the three viewpoints:
    - For the *hazard* point of view, experts need to know the probable local tsunami height, in order to derive submerged areas. Water heights are extracted from the PTWC alert message and pre-computed tsunami forecast models. Submerged areas are locally derived using LITTO3D Digital Terrain Model.
    - For the *potential issues* point of view, populations and infrastructures impacted by the tsunami have to be quickly identified. Infrastructures (e.g. buildings, roads) are extracted from the BDTOPO topographic database, and population density are derived from INSEE databases.
    - For the *risk* point of view, priority evacuations and secure areas should be identified, based on refuge sites and evacuation areas.
    - Additionally, rainfall at different periods of the crisis must be available to evaluate a potential amplified risk. Rainfall representations are generated from METEO FRANCE data.
- At the urban spatial scale, the task is “evacuation”: the experts need to plan the evacuation of people and boats. For this, they have to display the same type of information than at the local level but with more accuracy and reliability details.

We propose some multiplexing tools that can be associated with the scene, at each spatial scale, in order to help the experts in their decision-making:

- At the regional level, spatial and temporal multiplexing tools, such as swipe or animation, could be used to display more efficiently the wave progression and the Tsunami Travel Time.
- At the local level, spatial multiplexing tools can be implemented for mashing-up topographic, weather and temporal information to animate the rainfall.
- At the urban level, lenses and split/merge tools could be used to display risks information with different points of view.

IMPLEMENTATION : A TSUNAMI GEO-VISUALIZING PROTOTYPE USING MULTIPLEXING TOOLS

We implement the prototype using the Java language and two libraries: ZVTM (Pietriga, 2005) which is dedicated to the display of 2D representations on several screens (laptop, tablets, wall screens), and JavaFX to manage the interface[3].

Architecture of the prototype

The architecture of our prototype is described in Figure 7 and contains three major packages: one dedicated to the ZVTM library, one to the interaction with a PostGis database where data are stored (topographic or statistic data for example), and one dedicated to the Graphical User Interface (GUI). This last package is based on the Model View Controller (MVC) pattern.

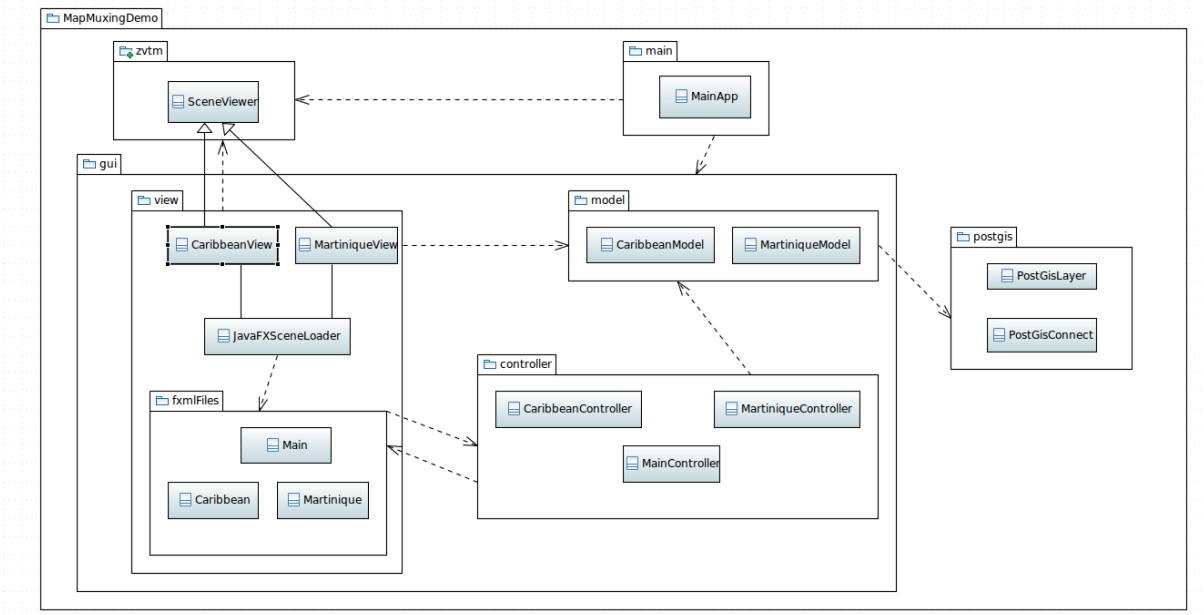


Figure 7 : Architecture of the prototype (UML package diagram)

Crisis unit user scenario at the regional level, the Caribbean region

We propose the following crisis unit user scenario, at the regional level, illustrated in Figure 8, when all of the frames are displayed: the screen is divided into several frames containing 1) a scene about Caribbean region for the hazard point of view on the left side, 2) the PTWC alert message on the right side (the message changes each time a new message is received), and 3) an overview to locate the scene in a largest region, on the bottom right side. This scene is composed by a tile map from the region (that can be changed by a menu), and some additional information about the earthquake (e.g. location and magnitude). The experts can see more information about the earthquake in an alert popup (4), by clicking on the epicenter placemark (5) or via a menu.

[3] http://www.oracle.com/us/technologies/java/050862.pdf

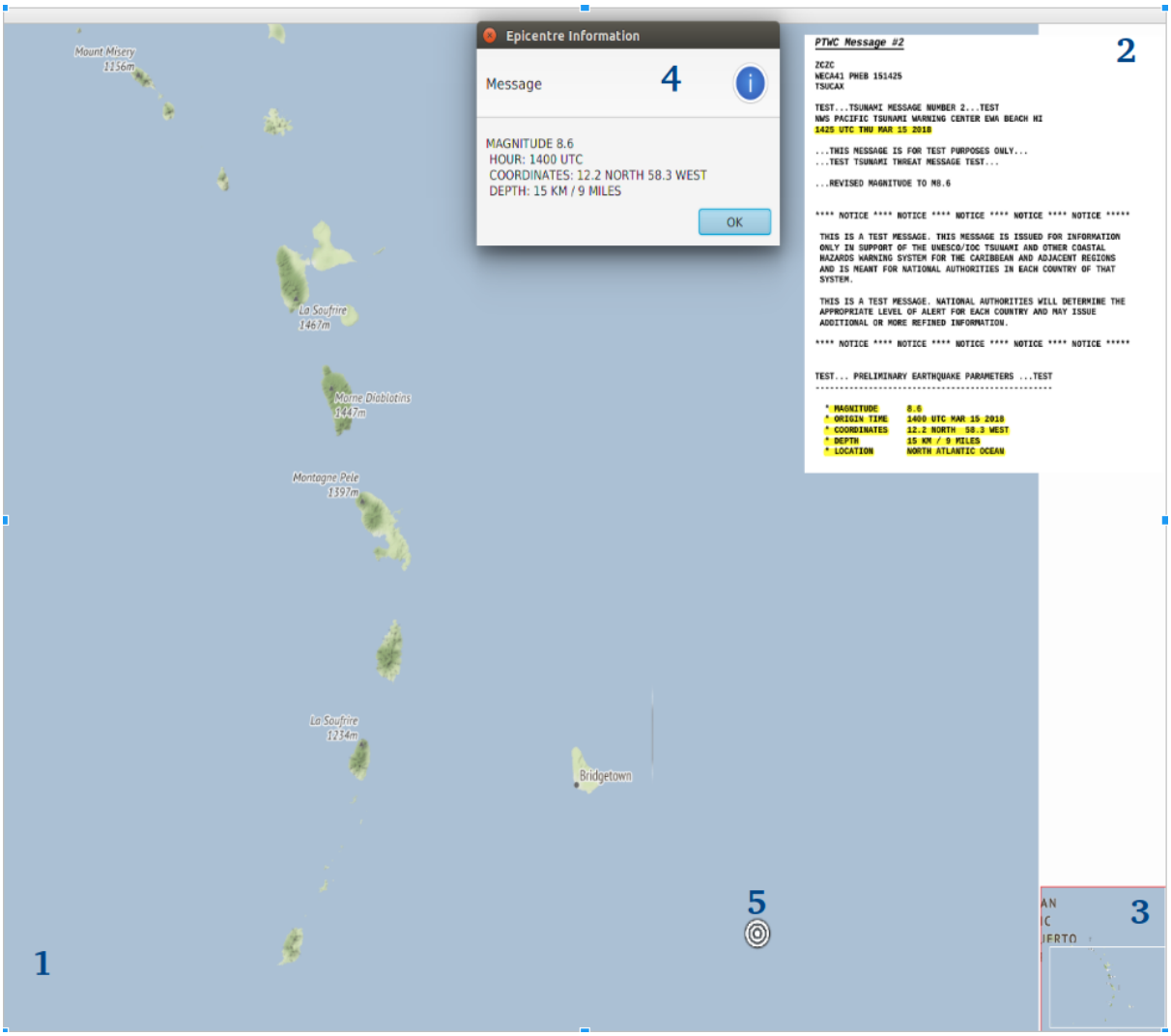


Figure 8 : Frames to be used for a user scenario at the regional scale: 1) Caribbean scene for the hazard point of view, 2) PTWC alert message, 3) Overview of a largest region, 4) Epicenter information, 5) Epicenter placemark

Additionally, experts can see via a menu, the Tsunami Travel Time (TTT) and the maximum predicted water height of the coast. This information gives the estimated time of arrival of the wave for all the Caribbean islands. Thus, they can decide to click on the Martinique island to see more information, and to decide where to dispatch the rescues. This action triggers the opening of a new frame on the Martinique scale.

Crisis unit user scenario: local level

The interface of the prototype is arranged in such a way that the frame of the Caribbean is not masked by the one of the Martinique (Figure 9). However, the main window is now the one of Martinique (but it is still possible to put forward the Caribbean one).

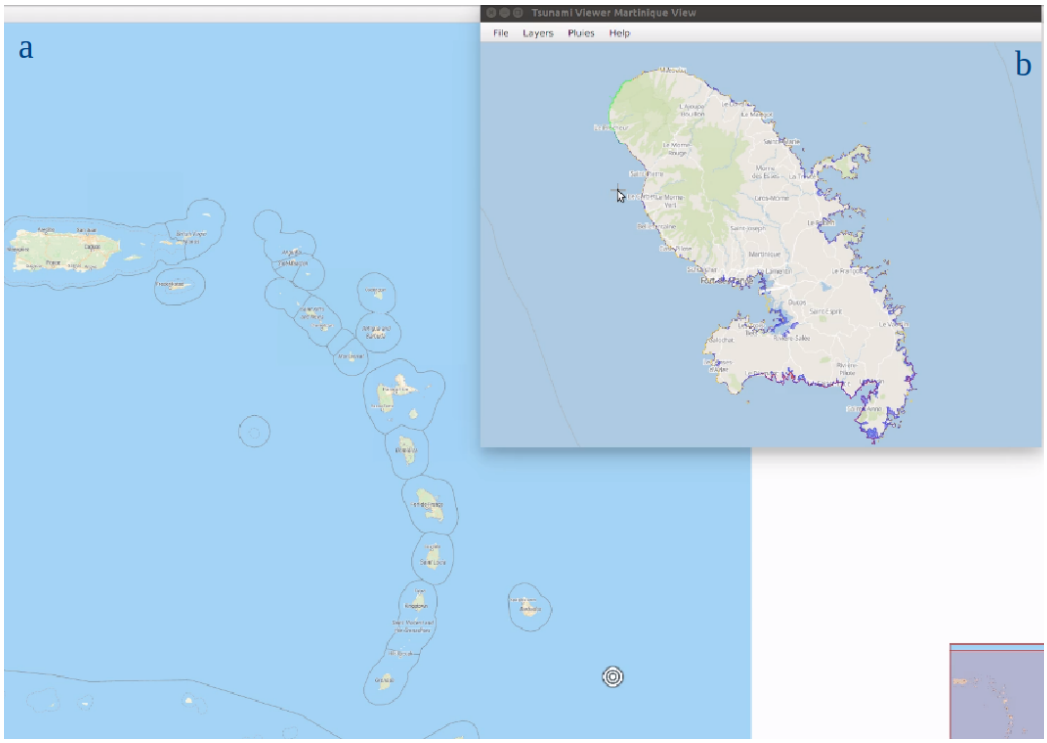


Figure 9: Space arrangement of the interface, with two frames at different scale: a) Regional scale, b) Local scale

The first frame displayed at the *Martinique* level is the hazard point of view (Figure 10a). At first sight, the experts can see the location of the main submerged area (colored in blue), and the water heights colored from green (low hazard) to red (significant hazard). By a menu, they can switch to the different viewpoints to navigate into scene from Hazard, Potential Issues or Risk. Figure 10b shows Potential Issues such as boats and buildings (in gray), and 10c shows the area to be evacuated (in green).

Figure 10: Martinique different scenes with: a) Hazard viewpoint, b) Potential Issue viewpoint and c) Risk viewpoint

Additionally, the experts can see the rainfall for each hour of the event (from 14h to 18h, figure 11b and 11c) or through an animation (Figure 11a). Rainfall accumulation for all day is also available. We use Meteo France semiology[4] to represent rainfalls, where in our simulation, light blue is less than 1mm and purple is higher than 10mm.

[4] http://www.meteofrance.com/previsions-meteo-france/simulations-numeriques-meteorologiques/france

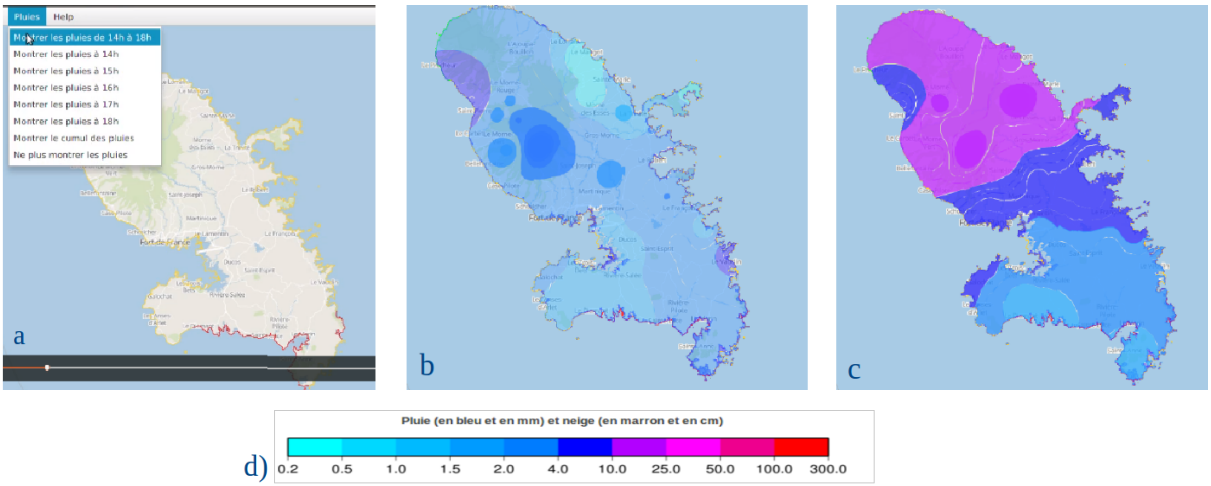


Figure 11: Rainfall animation during all the event (a), rainfall at 14h00 UTC (b), rainfall at 18h00 UTC (c) , and Meteo France scale semiology for rainfall display (d)

With all this information, the experts may notice that some strategic areas such as *Fort de France* town, the south of the island and the Atlantic ocean south coast will be more impacted by the tsunami than the north of the island. Thus, they have to zoom to these areas to check the potential issues and make the right decisions to keep people and boats safe. To illustrate this scenario, experts decide to click on the south of the island to see more details about the city of *Le Marin*.

Crisis unit user scenario: urban level

A new frame opens a display of an urban scene according to the hazard viewpoint. This new frame is located at the bottom left of the screen, allowing the visibility of both regional and local frames into the entire interface space (figure 12).

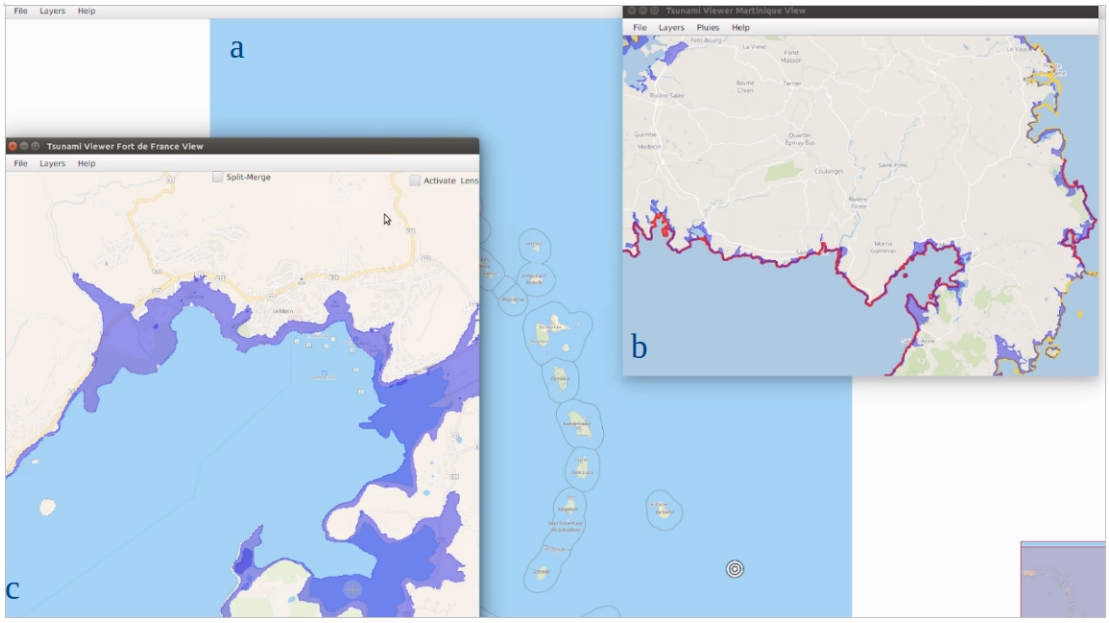


Figure 12: Frame spatial arrangement to see all scales : a) Regional level, b) Local level and c) Urban level

At this level, the experts may have to organize the pedestrian and boat evacuation. For that, they have to explore data from the three points of view (Hazard, Potential Issues and Risk). First, they may want to see data from two viewpoints in a single aggregated scene to assess which potential issues are impacted by the tsunami and evaluate how many people and boats to evacuate. To achieve this task, we propose to help the experts by the use of lenses multiplexing tool where one point of view is seen as the context and the over, inside the lens as the focus. Figure 13 gives an example of how we can use lenses at the urban level: in Figure 13-a, the *Potential*

Issue viewpoint is the focus inside the lens (showing people, road, buildings and boat that might be impacted by the wave), and the *Hazard* viewpoint is the context where we can see, the submerged area. In Figure 13-b, the context represents the *Potential Issues* and the focus is the *Hazard*. This example shows that the use of lenses can be potentially helpful in a crisis management context.

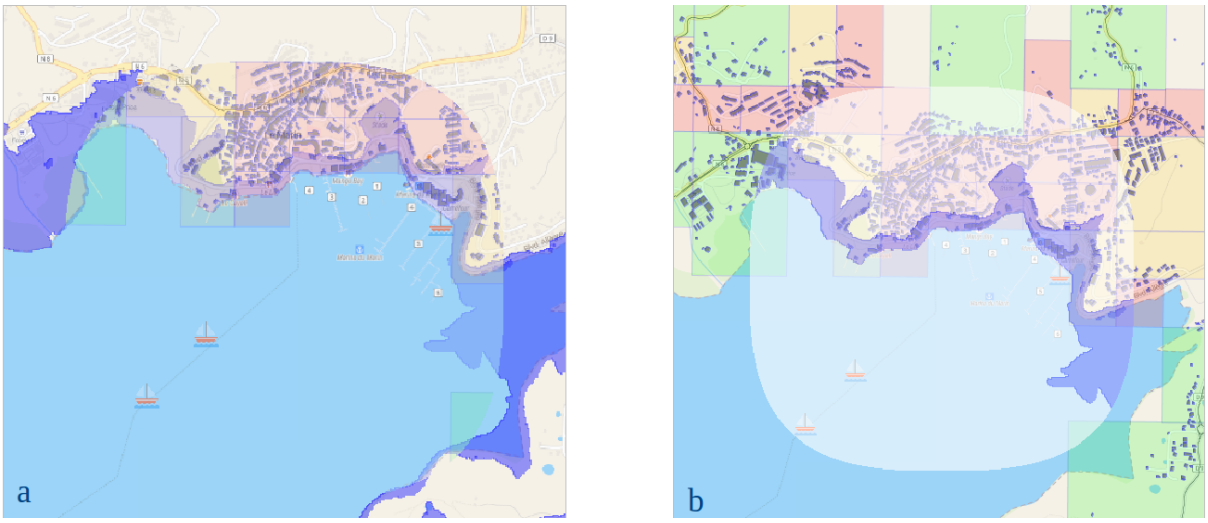


Figure 13 : Using lens to show different points of view into the same scene: a) Focus=Potential issues viewpoint, Context=Alea viewpoint; b) Focus=Alea viewpoint, Context=Potential issues viewpoint.

Additionally, the experts want to focus on the risk viewpoint to plan the evacuation. In this scene, superimposed datasets are displayed to the experts such as the population to evacuate (from green to red depending on the number of people impacted), submerged roads (in red), location of the refuge sites, or even boats to be evacuated offshore (Cf. Figure 14).

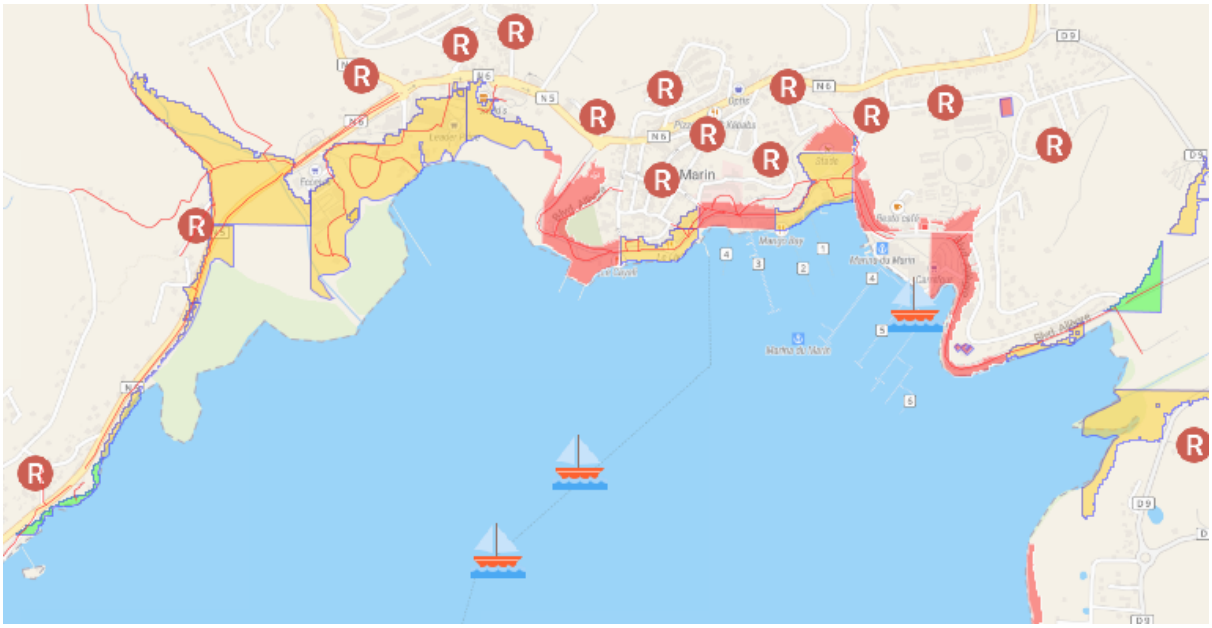


Figure 14 : Superimposition of several datasets for the risk point of view in the same scene

Visualizing all this superimposed information can lead to cognitive overload and is not efficient for the experts to perform their analysis in order to facilitate decision-making. To help the experts in this task, we propose to use a splitting multiplexing tool to break up the risk information into three distinct scenes: boats to evacuate, impacted population and submerged roads (Cf. Figure 15).

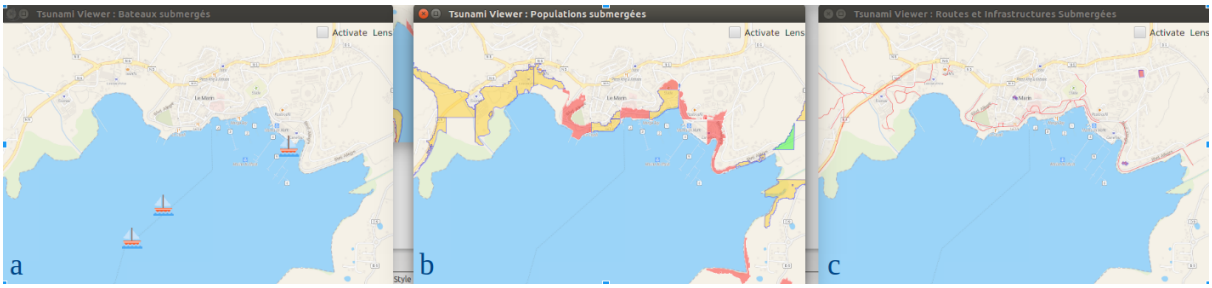


Figure 15 : Juxtaposition of scenes for the risk point of view by using a split/merge tool: a) boats to evacuate, b) impacted population, c) submerged roads.

By using this feature, the experts can focus on one major risk at a time, while keeping a view on other risks. With a menu button, the experts can easily switch from the merge to the split view. Using a split/merge multiplexing tool allows the experts to choose between aggregate or separate dataset. The separation reduces the graphic overload associated to the risk representation, and allows also experts to work collaboratively on different aspects of the crisis management. Additionally, expert can use a lens into one view to see for instance other information available (e.g. the refuge sites). We can easily assume that the use of a splitting multiplexing tool associated with a lens would be useful at the risk viewpoint to plan evacuation and lead people security.

DISCUSSION

The proposed model to manage multiple representations, as well as the developed prototype, already provide a formal framework for the co-visualization of information. Even if this contribution has not been completed by user tests, it offers potential answers to three limitations observed during our visits in crisis units:

- The difficulty to navigate efficiently from one visual representation to another,
- The difficulty of combining visual representations to extract new information,
- The impossibility of synchronizing spatio-temporal representations.

First of all, given that the proposed model formalizes the spatial relations between frames, it facilitates navigation between scales (as shown by the application example between Caribbean and Martinique representations), as well as the co-visualization of information on the same scale at the same time, using spatial multiplexing tools (for example using lenses).

Secondly, the formalization of spatial and semantic relations between scenes in the proposed model is supposed to facilitate the combination of information to deduce a new one. This has been illustrated by the crossing of hazards and issues to deduce elements at risk, but it was also observed in another visit on the intersection between atmospheric pressure and temperatures to deduce precipitations. As a perspective, it may be judicious to perform a user test in order to assess the capabilities offered by spatial multiplexing tools, such as lenses, to extract information inherited from multiple representations.

Finally, the model also proposes to formalize temporal relations between representations, which can be added to the spatial and semantic relationships already described. If the current model is conceptually able to link multiple representations by temporal relations, the operational implementation of these relations within the prototype is not yet effective. This question also raises issues related to the visual interpretation of the combination of animated phenomena. Indeed, it can on the one hand allow a crisis manager to anticipate (by observing the evolution of a phenomenon and by extending it cognitively), while also being able to disturb its capacity of decision-making because of the potential visual overload implied by these animated evolutions.

The current progress of this work leaves us to think that the field of crisis management can benefit from advances in terms of geo-visualization, and more particularly multiplexing techniques (spatial and temporal) to better manage heterogeneous representations used in an emergency and decision-making context. For this purpose, this work must be enriched with real uses cases experiments, in order to evaluate the benefits of the developed tools and methods to improve co-visualization of information for crisis management.

CONCLUSION

In this article we propose to explore spatial and temporal multiplexing techniques in order to improve co-visualization between visual representations of heterogeneous spatiotemporal data. This project is born during the visit of several crisis units. During these visits, we observed that many cartographic representations were

displayed on wall screens in order to facilitate the process of decision-making. However, we identified that these representations remained independent, which made navigation between representations difficult, and that the information represented remained difficult to combine, as it was often transmitted through raw data flows. If the visualization of these different representations could thus prove benefits in a context of crisis management, we could note that the lack of interdependence, and the impossibility of combining this information could also prove to disturb crisis managers. Therefore, we propose in this article (1) to elaborate a generic model allowing to formalize the relations (spatial, temporal and semantic) between representations, (2) to explore spatial and temporal multiplexing techniques in order to facilitate the co-visualization between heterogeneous spatiotemporal data, (3) to implement the model and the multiplexing techniques within a prototype software.

To illustrate the functioning of this prototype, we used a case study on a tsunami in the Caribbean region. Information on this scenario is coming from the *CARIBE WAVE 18* crisis exercise. This case study proved to be relevant to illustrate how the prototype works, since a tsunami can have catastrophic consequences over large areas in a very short time, which leads crisis managers to plan interventions on different areas. In terms of geovisualization, it involves experts to navigate between different scales of representation, and to combine different points of view (Hazards, Potential Issues and Elements at Risk). The proposed prototype, which includes a model for the formalization of the spatial relations between representations, associated with multiplexing techniques (spatial and temporal), offers a first contribution to manage these multi-dimensional constraints associated with the co-visualization of information for the crisis management.

Improvements still need to be integrated in these developments, particularly on the handling of the temporal dimension between representations, in order to allow experts to anticipate the consequences of a phenomenon in its dynamics characteristics. In addition, user tests should also be conducted in order to validate the benefits of the spatial and temporal multiplexing techniques in a crisis management context.

Obviously, this work leaves us to think that the field of crisis management can benefit from the advances in the fields of Geovisualization and Human Computer Interactions to better manage the co-visualization of information in a crisis management context related to natural disaster events.

ACKNOWLEDGMENTS

This research was funded by the french ANR MapMuxing program (ANR-14-CE24-0011-01). We want to particularly thank Meteo-France Martinique team who provided the climate data used for the prototype.

REFERENCES

Allen, T., Sanchagrin, S. et Lee, N. (2010). Geovisualization Strategies To Analyze and Communicate Inundation Risk From Storm Surges. Coastal Society 22nd International Conference, Wilmington, NC, USA.

Andrienko, N. and Andrienko, G.. 2005. Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach. Springer-Verlag, Berlin, Heidelberg.

Andrienko, G., Andrienko, N., Dykes, J., Fabrikant, S. I. et Wachowicz, M. (2008). Geovisualization of dynamics, movement and change: key issues and developing approaches in visualization research. Information Visualization, vol. 7, p. 173–180.

Bertin J. Semiology of Graphics. University of Wisconsin Press, 1983.

Bottger J., Brandes U., Deussen O., and Ziezold H. Map warping for the annotation of metro maps. In Visualization Symposium, 2008. PacificVIS '08. IEEE Pacific, pages 199–206. IEEE, Mar. 2008.

Boukhelifa N, Bezerianos A, Isenberg T (2012) Evaluating sketchiness as a visual variable for the depiction of qualitative uncertainty. IEEE Transactions on Visualization and Computer Graphics, 18(12):2769–2778.

Brosz, M. A. Nacenta, R. Pusch, S. Carpendale, and C. Hurter. Transmogrification: Causal manipulation of visualizations. In Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology, UIST '13, pages 97–106, New York, NY, USA, 2013. ACM.

Carpendale, M. S. T. (2003). Considering Visual Variables as a Basis for Information Visualisation. volume 2001-693-16. University of Calgary, Calgary, AB.

Cockburn A., Karlson A. & Bederson B. B. A review of overview+detail, zooming, and focus+context interfaces. ACM Comput. Surv. 41, 1 (2009), 2:1–2:31.

Dumont, M., G. Touya and C. Duchêne (2017) Alternative transitions between existing representations in

multi-scale maps, Proceedings of the 2017 International Cartographic Conference, Washington D.C., USA, July 2017.

Etienne L., Devogele T., Bouju A. Spatio-temporal Trajectory Analysis of Mobile Objects Following the same Itinerary. Advances in Geo-Spatial Information Science, Chapter Modeling Space and Time, 2012.<hal-01740733>

Gierlinger, T., Brodtkorb, A. R., Stumpf, A., Weiler, M. et Michel, F. (2015). Visualization of Marine Sand Dune Displacements Utilizing Modern Gpu Techniques. ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 1, p. 503–508.

Harrower, M., & Brewer, C. A. (2003). ColorBrewer.org: An online tool for selecting colour schemes for maps. Cartographic Journal, 40(1), 27-37. https://doi.org/10.1179/000870403235002042

Hoarau C., Christophe S. (2017). Cartographic continuum rendering based on color and texture interpolation to enhance photo-realism perception ISPRS Journal of Photogrammetry and Remote Sensing, vol. 127, May 2017, pp. 27-38. http://dx.doi.org/10.1016/j.isprsjprs.2016.09.012.

Jakobsen M.R., Y. Sahlemariam Haile, S. Knudsen, and K. Hornbaek. Information visualization and proxemics: Design opportunities and empirical findings. Visualization and Computer Graphics, IEEE Transactions on, 19(12):2386–2395, Dec. 2013.

Karnick P., Cline D., Jeschke S., Razdan A.,Wonka P., "Route Visualization Using Detail Lenses," in IEEE Transactions on Visualization and Computer Graphics, vol. 16, no. 2, pp. 235-247, March-April 2010. doi: 10.1109/TVCG.2009.65

Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J. et Melançon, G. (2008). Visual analytics: Definition, process, and challenges. Information Visualization, Springer Berlin Heidelberg, p. 154-175.

Konecny, M., Zlatanova, S., Bandrova, T. (2010). Geographic information and cartography or risk and crisis management. Lecture Notes in GeoInformation and Cartography. Springer-Verlag Berlin Heidelberg.

Leskens, J. G., Kehl, C., Tutenel, T., Kol, T., Haan, G. d., Stelling, G. et Eisemann, E. (2015). An interactive simulation and visualization tool for flood analysis usable for practitioners. Mitigation and Adaptation Strategies for Global Change, p. 1-18.

Lobo, M., Pietriga, E. and Appert, C. (2015). An Evaluation of Interactive Map Comparison Techniques. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15). ACM, New York, NY, USA, 3573-3582. DOI: https://doi.org/10.1145/2702123.2702130

MacEachren, A.M., Kraak, M.-J. (2001) Research Challenges in Geovisualization. Cartography and Geographic Information Science 28(1), 3–12.

Marcy, D., Brooks, W., Draganov, K., Hadley, B., Haynes, C., Herold, N., McCombs, J., Pendleton, M., Ryan, S., Schmid, K., Sutherland, M. et Waters, K. (2011). New Mapping Tool and Techniques for Visualizing Sea Level Rise and Coastal Flooding Impacts. Solutions to Coastal Disasters Conference, Anchorage, Alaska, USA.

Medley, S., Haddad, H., (2011). The Realism Continuum, Representation and Perception. The International Journal of the Image 1 (2), 145–156.

Mengguo, L., Dongming, C., Zheng, Z. et Bei, L. (2000). A 2D Tidal Current Visualization Mathematical Model for Coastal and Estuarine Waters. Marine Science Bulletin-Tianjin, vol. 19, p. 57–65.

Murphy, C., Aug. 2015. Intellectual Highlighting of Remote Sensing Imagery for Better Image Map Design. 27th International Cartographic Conference, 2015.

Nicholls, R. J. et Cazenave, A. (2010). Sea-level rise and its impact on coastal zones. Science, vol. 328, p. 1517–1520.

Patterson, T and Jenny, B (2013), 'Evaluating cross-blended hypsometric tints: A user study in the United States, Switzerland, and Germany', *Cartographic Perspectives*, no. 75, pp. 1-11.

Patterson, T. and N.V. Kelso. (2004). "Hal Shelton Revisited: Designing and Producing Natural-Color Maps with Satellite Land Cover Data." Cartographic Perspectives 47: 28–55.

Perin, C., Dragicevic, P., and Fekete, J.-D. (2014). Revisiting Bertin matrices : New Interactions for Crafting Tabular Visualizations. IEEE Transactions on Visualization and Computer Graphics.

Pietriga E. (2005), A Toolkit for Addressing HCI Issues in Visual Language Environments. Proceedings of the 2005 IEEE Symposium on Visual Languages and Human-Centric Computing (VLHCC*)*, Dallas, TX, USA, 2005, pp. 145-152.

Pietriga E., Bau O. & Appert C. Representation-Independent In-Place Magnification with Sigma Lenses. IEEE TVCG 16, 3 (2010), 455–467.

Pindat C., Pietriga E., Chapuis O., Puech C. (2012). JellyLens: Content-Aware Adaptive Lenses. Proceedings of the 25th Symposium on User Interface Software and Technology, Oct 2012, Cambridge, MA, United States. ACM, pp.261-270, 2012, UIST '12.

Porter, T., Duff, T., 1984. Compositing digital images 18 (3). In: ACM Siggraph Computer Graphics. ACM, pp. 253–259.

PTWC (2018) : EXERCISE CARIBE WAVE 18. A Caribbean and Adjacent Regions Tsunami Warning Exercise. Participant Handbook. *Intergovernmental Oceanographic Commission technical series.*

Raposo P. & Brewer C. Comparison of topographic map designs for overlay on orthoimage backgrounds. In International Cartographic Conference (2011), 3–8.

Reilly D.F. and Inkpen K. M. Map morphing: Making sense of incongruent maps. In Proceedings of the 2004 Graphics Interface Conference, GI '04, pages 231–238, School of Computer Science, University of Waterloo, Waterloo, Ontario, Canada, 2004. Canadian Human-Computer Communications Society.

Rensink, R. A., O'Regan, J. K. et Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. Psychological science, vol. 8, p. 368–373.

Semmo, A., Trapp, M., Kyprianidis, J. E. and Döllner, J., 2012. Interactive Visualization of Generalized Virtual 3D City Models using Level-of-Abstraction Transitions. Computer Graphics Forum.

Semmo, A. et Döllner, J. (2014). Image Filtering for Interactive Level-of-abstraction Visualization of 3D Scenes. Workshop on Computational Aesthetics, Vancouver, British Columbia, Canada.

Slocum TA, McMaster RB, Kessler FC, Howard HH (2009) Thematic cartography and geovisualization. Prentice Hall series in geographic information science. Prentice Hall

Spekat, A. and Kreienkamp, F. (2007). Somewhere over the rainbow; advantages and pitfalls of colourful visualizations in geosciences. Advances in Science and Research, 1(1):15-21.

Tateosian, L., Mitasova, H., Thakur, S., Hardin, E., Russ, E. et Blundell, B. (2014). Visualizations of coastal terrain time series. Information Visualization, vol. 13, p. 266-282.

Thyng, K. M., Greene, C. A., Hetland, R. D., Zimmerle, H. M., and DiMarco, S. F. (2016). True colors

of oceanography : Guidelines for effective and accurate colormap selection. Oceanography, 29.

Tominski C., Gladisch V, Kister U. , Dachselt R. , Schumann H.. 2017. Interactive Lenses for Visualization: An Extended Survey. Comput. Graph. Forum 36, 6 (September 2017), 173-200. DOI: https://doi.org/10.1111/cgf.12871.

Trapp, M., Beesk, C., Pasewaldt, S. and Döllner, J., 2011. Interactive rendering techniques for highlighting in 3d geovirtual environments. In: T. H. Kolbe, G. K¨onig and C. Nagel (eds), Advances in 3D Geo-Information Sciences, Lecture Notes in Geoinformation and Cartography, Springer Berlin Heidelberg, pp. 197–210.

Thiede, C., Fuchs, G., Schumann, H.: Smart Lenses. In Proc. of Smart Graphics (SG) (2008), Springer, pp. 178–189. doi:10.1007/978-3-540-85412-8_16.

Van Oosterom, P., Zlatanova, S., Fendel, E., 2005. Geo-information for disaster management. Springer-Verlag Berlin Heidelberg

Ware C. & Lewis M. The DragMag Image Magnifier. CHI '95 companion, ACM (1995), 407–408

Van Wijk, J. J., Nuij, W. A. (2003).“Smooth and efficient zooming and panning,” in Information Visualization, 2003. INFOVIS 2003. IEEE Symposium on, 2003, pp. 15–23.

Yang, Z., Wang, T., Cline, D. et Williams, B. (2014). Hydrodynamic Modeling Analysis to Support Nearshore Restoration Projects in a Changing Climate. Journal of Marine Science and Engineering, vol. 2, p. 18-32.

Yi, J. S., ah Kang, Y., Stasko, J. T. et Jacko, J. A. (2007). Toward a deeper understanding of the role of interaction in information visualization. IEEE Transactions on Visualization and Computer Graphics, vol. 13, p. 1224–1231.

Semantic Understanding of Human Mobility Lifestyle to Support Crisis Management

Humasak Simanjuntak
University of Sheffield
htasimanjuntak1@sheffield.ac.uk

Fabio Ciravegna
University of Sheffield
f.ciravegna@sheffield.ac.uk

ABSTRACT

In this paper, we propose a method for understanding the semantics of mobility (mainly related to lifestyle) patterns based on stay point detection from tracking data. The method identifies the context (trip purpose and visited point of interest) of tracking data by using large-scale data collection infrastructure. We evaluate our method with a tracking dataset in Birmingham (European project SETA) generated by 534 users from September 2017 to September 2018. To this end, we compare insights from the tracking data with check-in mobility in social media. The results show that both data capture rich human lifestyle features related to the visited point of interest. Our study provides solid evidence that lifestyle patterns from tracking and social media data can indeed be useful for understanding and gauging the level of disruption after a crisis, as it is possible to check the deviation of habits from normal conditions and post-crisis.

Keywords

lifestyle patterns, mobility patterns, semantic annotations, semantic mobility.

INTRODUCTION

Disaster severity and frequency trends have risen significantly in recent decades. Understanding human mobility, specifically lifestyle patterns is crucial for crisis responders and policymakers in determining effective strategies for disaster response, especially recovery or evacuation plans (Wang and Taylor, 2016). These lifestyle patterns are related to spatial and temporal regularity. Spatial regularity means a person is going to similar places or point of interest (POI); temporal regularity can be considered as when a person visits the same POI at a similar time of the day. Natural disasters such as earthquakes, storms, etc. are serious threats to urban areas affecting daily lifestyles because such events can devastate public infrastructure usually visited by people. Adjusting lifestyles to deal with crisis events can be problematic. Therefore, understanding human daily life pattern changes such as trip purpose and use of public infrastructure (shopping malls, food places, stations, etc.) will enable decision makers to monitor and analyse the impact of any disaster in the urban area, providing advantages for risk assessment, preparedness, emergency management and plans for recovery or reconstruction actions primarily related to the needs of citizens, such as where to obtain supplies of food and clothing.

Recently, technologies have been developed to capture human mobility data. The movement of people may be tracked and recorded in real time easily using wireless and sensor technology. Apps created by big companies such as Google, Apple, and Facebook collect our daily patterns of regularity related to place and the time spent there. Furthermore, with the increased popularity of social media, a large amount of check-in data can also be used to capture human mobility. Learning and understanding this data can help to analyse lifestyle patterns related to a crisis event. However, the accuracy, sparsity and semantic representation of tracking data pose challenges in understanding lifestyle patterns. Raw tracking data in the form of a time sequence of locations are not easily understandable without semantic representation.

Human mobility analysis has been applied to support crisis management using crowdsourcing (Ludwig et al., 2017), GPS data (Song et al., 2017), and social media (Xiao, Huang and Wu, 2015). Furthermore, effective models for simulating and predicting human movement after a crisis have been proposed (Song et al., 2015, 2017). However, there is still a lack in previous studies related to understanding human mobility to support

crisis management. Most are concerned with specific mobility data. They only use tracking data (GPS trajectory), transportation networks, CDR or social media, but do not integrate these data to give more insight into daily urban life patterns. By incorporating these data, habit deviation from normal and post-event, the changes in crowd mobility, levels of disruption after an event can be assessed accurately to support crisis management. If mobility and distribution patterns can be efficiently identified then post-crisis risk can be minimalised, crisis responders or rescue resources will arrive on time, understand what the population needs, how the different part of a city are connected and provide better evacuation plans. Specifically, the research uses GPS trajectory data only focused on motorised mobility (ex: using taxi trajectory) and does not discuss other types of mobility (walking, running, cycling, etc.). It does not explain detailed semantics of mobility such as the associated behaviour to the mobility, trip purpose or how the population use the POI.

This work aims to identify semantic mobility patterns in the metropolitan area from two datasets: tracking and social media data. The tracking data collected by apps (iOS and Android apps as a part of the European project SETA, http://setamobility.weebly.com/) that track multimodal mobility patterns in three cities (Birmingham, Santander, Turin). Since social media data relationships could explain 10%-30% of all human movement (Cho, Myers and Leskovec, 2011), we compare the patterns in tracking data with check-in patterns found in social media data. 'Check-in' refers to the specific time and location of a particular user shown by use of online social applications.

In this study, we present a method to build semantic mobility patterns from tracking data. We develop a model to discover trip purpose and important places in people's daily life based on stay point. The model will allow the analysis of human daily lifestyle patterns, when or where people use public infrastructure such as shopping malls, food places, stations, etc. Furthermore, knowledge of everyday patterns allows understanding of the citizen's needs (where they get supplies (e.g. food, clothing), where they go at the weekend, how the different parts of the city are connected, etc.). Specifically, it also shows and gauges the level of disruption after an event, as it is possible to check the deviation of habits from a normal situation and post-event. This detailed information is very useful for decision makers or policymakers.

In summary, the contributions of this paper are:

- We study an important and challenging problem of understanding human lifestyle patterns in tracking data records. We build context annotations that help bridge the gap between raw tracking data and surrounding contexts and hugely enrich our understanding of mobility data.
- Different from existing studies on human mobility for crisis management which do not consider detailed semantics of mobility, we propose a semantic model to capture meaningful user activity based on stay points and type of location visited.
- We conduct experiments on large-scale mobility datasets in Birmingham (534 users in tracking data and 116,468 users in social media).

Below, we discuss related work and challenges in understanding human mobility in crisis events. Next, we describe heterogenous datasets used in this research. We present a method for identifying human semantic mobility in the system overview and framework section. The results of our experiment are discussed in the Results and Discussion section. Finally, we conclude the paper and provide some directions for future work.

RELATED WORK

A number of studies have been made on how mobility patterns can be utilised to supporting crisis management by applying techniques such as crowdsourcing, GPS data, and social media. Many studies have employed the content of social media such as tweets to identify irregularities in human movements or communication before, during, and after disasters (Hong, Fu, Torrens and Frias-Martinez, 2017; Kumar and Ukkusuri, 2018; Xiao, Huang and Wu, 2015). Other researchers have proposed a general model to identify human post-crisis movement patterns based on mobile GPS data (Song et al., 2015, 2017). Call Detail Records (CDR) have also been used by researchers to explore communication behaviour changes caused by disasters, especially in particular locations where resources for evaluating mobility behaviours are rarely available (Hong, Mashhadi and Frias-Martinez, 2018). While these studies present in-depth investigations of large-scale human mobility, they often focus on specific types of disaster without considering other potential considerations in the aftermath of crises such as the dynamics of population lifestyle in the affected area (how the citizens use POI in the affected area).

Another stream of work developed a model to predict human mobility during or after a crisis. Song et al (Song et al., 2015) proposed an effective model based on a Hidden Markov Model to predict human mobility following disasters, the Great East Japan Earthquake and Fukushima nuclear accident, based on GPS records, news, and

transportation networks. Recently, a deep learning framework was developed to predict regular and irregular human mobility during rare events in the city from historical GPS data (Fan et al., 2018). These prediction models, however, usually lack semantic understanding of mobility because they did not consider transportation mode - stay, walk, bicycle, car, train - and were not associated with other context data such as POI, weather, or event information which could provide detailed knowledge to boost prediction accuracy.

The most similar work to this paper examined a process to annotate raw tracking data with some contextual sources. Adding semantic annotations is a key for human mobility analysis, especially finding behaviour patterns from tracking data. Point-of-Interest Extraction (PIE) Algorithm annotated stay points in indoor activities by defining parcel polygons and polygons-of-interest (de Graaff, de By and van Keulen, 2016). Furthermore, a framework which combined trajectory segmentation (move or stop) with contextual information (OpenStreetMap[1] and Ordnance Survey UK[2]) examined the type of place visited by the volunteered GPS trajectories (Siła-Nowicka et al., 2016). Other works also studied the function of each region (zones) in a city using a topic modelling approach based on taxi trajectories and POI data (Yuan, Zheng and Xie, 2017). The method annotates functional zones with semantic terms by calculating an average POI feature vector (rank POI category in a zone) and frequently observed mobility pattern in each zone. In addition, research related to mobility based on check-in location in social media has also been conducted. Constructing a tourist travel diary in Hongkong based on POI check-in obtained detailed trip and contextual information reflecting tourist activities (Vu et al., 2017). Chao et al analysed college community patterns in Wuhan based on geotagged Weibo messages (Yan et al., 2018).

HETEROGENEOUS DATA SOURCES

In this work, we employ various data sources to build semantic understanding of human mobility to support crisis management; they can be summarized as follows:

- **Tracking Data:** We collected tracking data from thousands of users in Birmingham, Santander, and Turin from September 2017 - September 2018. As a case, we use tracking data from 534 users in Birmingham. The SETA apps have been distributed to the citizen with some social economic category (a specific type of population). Users are voluntary and entirely aware that they are being tracked for research purpose. Data were collected and managed by large scale architecture that provide query processing, integrated processing, Reliability, Data Privacy, and Security. The framework and architecture for data collection were discussed in the previous research (Ciravegna et al., 2018)
- **Social media data:** We extracted check-in data in Birmingham, UK from the geo-located tweets (Twitter) of 116,468 users from September 2017 to September 2018.
- **POI database:** We built a POI database based on data from Foursquare[3] and google places[4]. The data contain information about POI, such as name, location, POI category, opening times.
- **OpenStreetMap Database:** We used the UK OpenStreetMap database to map tracking data with potential stay points.
- **Postcode database:** We used the UK postcode database to map stay points with the nearest postcode.

SYSTEM ARCHITECTURE AND FRAMEWORK

In this section, we describe the system architecture for developing a semantic understanding of human mobility from tracking data to support crisis management. As explained above, the framework and data collection infrastructure has been discussed in previous research (Ciravegna et al., 2018). Therefore, the following system architecture (Figure 1) focuses on the data processing method.

[1] https://www.openstreetmap.org/
[2] https://www.ordnancesurvey.co.uk/
[3] https://foursquare.com/
[4] https://cloud.google.com/maps-platform/places/

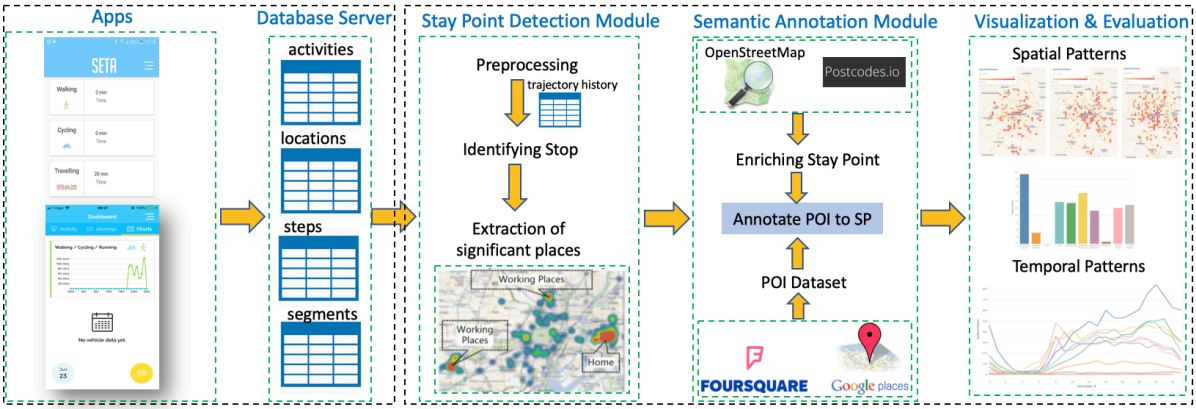


Figure 1 System Architecture & Framework

Our framework comprised four components: Data Collection Tool; Stay Point Detection Module; Semantic Annotation Module; and Visualization and Evaluation module. The detailed description of each part is explained in the following sub section.

Data Collection Tool

The SETA app is a mobile application that monitors a person's movement and presents a summary and breakdown of their day so that a user can track their level of mobility. The app tracks vehicular and active mobility to allow the next analysis related to lifestyle patterns such as stay point or trip purpose that refer to the points of interest. This application captures data from mobile phone sensors, such as accelerometer, GPS (location), and pedometer (steps). Data from multiple sensors are analysed and combined to produce segments of activity such as walking, cycling, and running, including step counts, time of activity started and ended, and individual locations (latitude, longitude).

The apps fuse individual tracking data, sent to the server and immediately stored in a database. The final dataset collected is extracted, validated, analysed and filtered to form tables which store data about activity, locations, segments, and steps.

Stay Point Detection Module

Real tracking data are often not accurate, due to noise, missing, or incomplete data. Processing this low-quality data will lead to poor results. The pre-processing step is performed to provide clean and valid data to obtain useful features. Any duplicate record is removed, the timestamp locations checked with excluded locations with the same timestamp. The pre-processing step also does temporal alignment by aligning raw data (activities, locations, steps, and segments) captured from different phone sensors into one history table. The alignment process classifies locations into activity segments based on the location timestamp. All locations between activity segment start time and end time are classified as one location segments and then the activity is attached to the location. The segments categorised in 6 activities are Vehicle, Cycling, Stationary, Other, Walking, and Running.

Stay point is the set of geographical points where a person stays for a while within a certain distance threshold. In general, stay point can be represented as a set of consecutive GPS locations $L=\{l_m, l_{m+1}, l_{m+2}, \ldots, l_n\}$ *where* $\forall_i$, $m< i\leq n$, $distance(l_m, l_n)\leq dthreshold$ *and* $|duration(l_m, l_n)|\geq tthreshold$. The distance between two geographical locations is computed by using the Haversine formula and the time span between two location points is defined as stay duration. Stay point plays a major role in adding a context or semantic meaning to trajectories. Identifying the stay points allow us to segment the trajectory to be a stop or move, determine mode transition e.g. walking to bus, and infer trip purposes by associating it with POI information.

We develop an algorithm based on the PIE algorithm (de Graaff, de By and van Keulen, 2016) and the algorithm proposed by Li et al (Li et al., 2008) to obtain stay points from tracking data. The procedure to acquire stay points from tracking data can be seen in algorithm 1 (see Figure 2).

Algorithm 1 Stay Point Detection

INPUT:
1. *UT* = list of user trajectories {<lat,lon,t,seg>, <lat,lon,t,seg>, ...<lat,lon,t,seg>}
2. *eps*, the stay point distance threshold in meters
3. *t*, the stay point duration threshold in millisecond

OUTPUT:
1. SP = {sp_1, sp_2, ..., sp_m} the list of stay points
2. Clustering of Stay Point
3. Home Place

begin
  for each user **do**
    //Remove inaccurate locations that greater than the average of accuracy
    listLocationsPoints = $\{l_p \in UT \mid l_p.a \leq avg(a)\}$

    //Get candidate stay points for each day
    listCandidateStayPoints = *getCandidateStayPoints (listLocationsPoints, eps, t)*

    //Cluster candidate Stay Point by applying DBSCAN and generate centroid
    listStayPointCluster = *getClusterDBSCAN (listCandidateStayPoints)*

    //Generate summary of stay point (occurrence, days, duration)
    listSummarySP = *generateSummarySP (*listStayPointCluster*)*

    //define some significant places: home, SP1, SP2, SP3, etc
    defineHomePlace(stayPoints, summarySP)
end

Figure 2 Algorithm to extract stay points

The algorithm works by retrieving a sequence of locations for each user trajectory. The inaccurate locations are removed based on the average of location accuracy in the data. The stay point candidates for each user are generated by considering the distance and duration threshold parameters. We also consider the type of location segment in deciding stay point candidates. The '*stationary segment'* means that users stop in certain locations for a certain time based on segment timestamp. We focus only on the stay point where the user stays for equal to or more than to 5 minutes and not give much attention to shorter stay points such as traffic light stops, traffic at roundabouts, etc.

The stay point candidates are location clusters which consist of one or more stop locations. Even though the most inaccurate locations are already previously removed, the stop locations could contain locations outside of the POI. Therefore, we utilise DBSCAN algorithm (Ester et al., 2008) with parameter *eps=30 meters* and *minPts=5* to get more accurate locations in the stay point and get a better centroid of the cluster based on remaining stay point locations.

For spatial and time regularity, we record features such as frequency, day, arrival time, leaving time, and stay duration to produce a summary of user stay points. We also create Origin-Destination matrices based on stay point to get detail journey of the user. We use this summary to detect Home place and extract other significant places. Home is considered the place where a person spends most of his/her time. Therefore, the rules for defining Home are:

i. The most frequently visited place with the most total duration of visits.
ii. The start and end location for every day.
iii. There should be at least 5 stop locations per week in the stay point.

We aggregated and clustered stay points for each user by temporal features (time, day) and spatial features (POI category, postcode) to understand human lifestyle patterns. Knowing daily patterns of citizens is critical to allow us in measuring the level of disruption after a crisis, as it is possible to monitor the deviation of the habit before and after the event. Figure 3 shows the distribution of stay points (on weekdays and weekends), with the sizes of the circle indicate number of stay points at the POI.

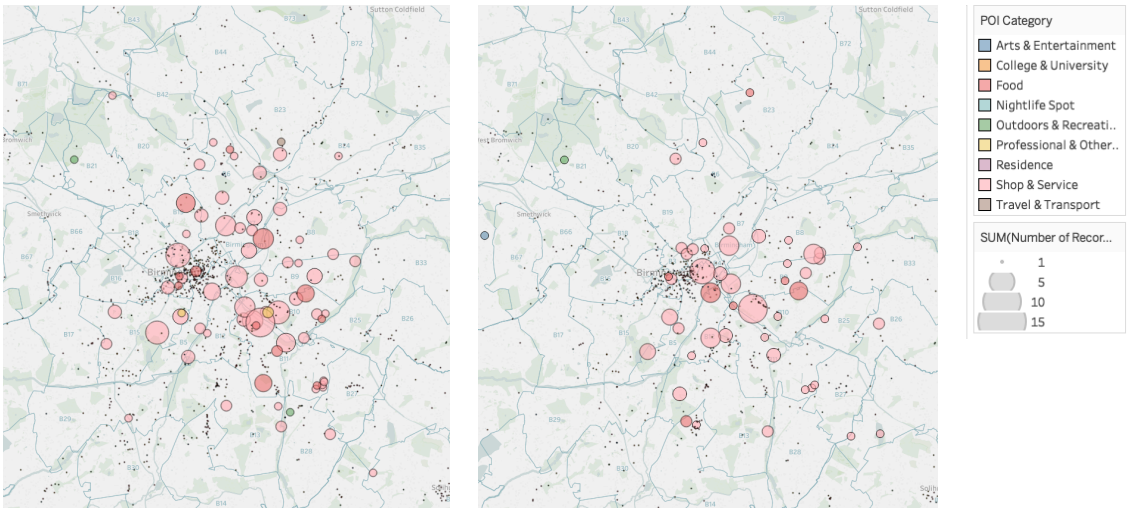


Figure 3 Distribution of stay point for weekdays (left) and weekend (right)

Semantic Annotation Module

Semantic annotation is a process of adding context to the stay point so we can classify it to the certain POI. We want to analyse which POI motivated stops in the stay point during the trip. There are two subprocesses to semantically annotate the individual trajectories: enriching stay points with additional data from OpenStreetMap and postcode.io[5]; and finally, annotating POI to the stay point.

To get more meaningful knowledge about activity label, we enriched stay point with related contextual information, such as OpenStreetMap and postcode. We mapped the stay point to the OpenStreetMap data by exploiting the information around the stopping place to get POIs nearby, land use, or amenity information. We utilized spatial relationship features supported by the PostGIS[6] database to determine if a stay point was entirely inside another geometry (polygon) or within the specified distance (maximum 100 m) of points or polygons representing the POIs. If this condition was fulfilled, then we assigned a name of POI nearby, land use, and amenity information (the nearest POI within 100m is assigned to the stay point which is not inside of another polygon). We also assigned postcode information to the stay point based on the nearest postcode.

The last process in building semantic annotation to the stay point is classifying stay point to the POI.

The POI dataset enables us to model the functionality of each area in the city. POI dataset gives some information about the venues, such as name, category, coordinate, opening times, and a bounding box. We built POI dataset based on data from Foursquare, OpenStreetMap, and google places. The POI dataset comprises 10 categories: *arts & entertainment, college & education, event, food, nightlife, outdoors & recreation, professional, residence, shops travel and transport*.

We queried foursquare Places API to collect POI information in Birmingham city with bounding box [{'south west': '52.381054, -2.033649', 'north east': '52.608707, -1.728858'}]. To cope with a limited request in the API, we used the technique introduced by Fei et all (Fei Wu, 2016). For each search query, the API returns at most 50 POIs. We performed recursive steps by partitioning the Birmingham map into smaller grids (four partitions for each iteration) if a query on the map or current grid returned 50 POIs. As a result, we obtained 19122 POIs. Figure 4 shows the distribution of POI categories in Birmingham City.

[5] http://postcodes.io/
[6] https://postgis.net/

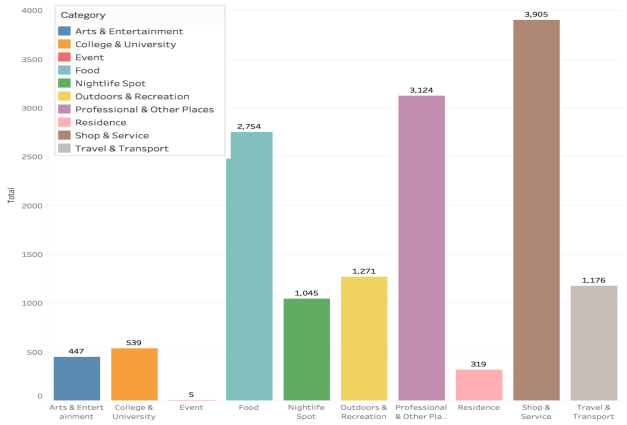


Figure 4 POI distribution in Birmingham, UK

Based on the defined POI dataset, the stay point is annotated with POI category. Home stay points located in residential areas are excluded from further analysis. The semantic annotation rule is applied by combining the distance-based method and contextual information previously found from OpenStreetMap. Other stay points are annotated with the POI based on the nearest distance, highest similarity POI name to the stay point and the arriving time in the range of POI opening times.

The algorithm to build semantic annotation to the stay point can be seen in the following algorithm (Figure 5).

Algorithm 2 Annotate Semantic SP

INPUT:
1. *SP*= list of significant places {<list stay point>,...}, *SSP=summary stay point {<summary SP>}*
2. *OpenStreetMap Data*
3. *POI database*

OUTPUT:
1. SSP = {sp_1, sp_2, ..., sp_n} the list of semantic stay points

begin
for each SP **do**
//enrich the stay points with postcode
SSP=getPostcode(stayPoint centroid)

enrich the stay points with OSM by considering spatial relationship
SSP = enrichStayPoint(listSummarySP)

$$\left\{ \begin{array}{l} sspI \in SSP \mid distance(sp, polygon) = 0 \vee distance(sp, polygon) < eps \vee \\ \qquad\qquad\qquad\qquad distance(sp, point) < eps \end{array} \right\}$$

//Add semantic to the stay points by considering same name and nearest POI
If not Home and not Land-use residential:
SSP=getSemanticSP(SPname, arrivalTime, POI Database)
end

Figure 5 Semantic annotation algorithm

Visualization and Evaluation Module

Semantic POI finds in the tracking data are visualized via a faceted browsing interface. We show the statistic on how the population in Birmingham used POI in the city and visualized the spatial distribution in the map. We also use this module to visualize POI check-in from social media. Such information is very useful for identifying the distribution of population during an emergency and therefore the number of people affected in each area.

EXTRACTING POI CHECK-IN FROM SOCIAL MEDIA

Location-based services in social media applications facilitate people sharing their check-in places (Cho, Myers and Leskovec, 2011). The check-in information contains geotagged venue and its geolocation attribute which are very useful in identifying human movement behaviour. Mobility pattern can be understood from social media data by extracting check-in tweets to get information about activity purpose. The activity purpose is inferred based on the category of the visited POI appearing in the tweet. Furthermore, the spatial distribution of popular places is represented by considering the total number of check-ins for different POI category and the popularity over time for those POI categories is considered as temporal distribution.

In this paper, we use 2,876,645 geotagged tweets from 116,468 users in Birmingham, UK from September 2017 to September 2018. We recorded geo-located tweets using Twitter search and streaming API[7]. After collecting this dataset, we selected the subset of tweets containing check-in word and Instagram. As a result, we obtained 43,971 check-in tweets for our analysis. Based on our observation, we extracted the check-in tweets by defining the strategy below:

i. Check-in tweet contains check-in words: ["I'm @", "I'm at", "I am @", "I am at", "arrived at", "arrived @", "I am in front of", "I'm in front of", "I'm going to", "I am going to"] followed by POI name.
ii. POI name in the check-in tweet is matched with POI name in POI database if:
    a. the distance between the geotagged tweet and POI coordinate is within 100 meters and
    b. the similarity between POI name is large or equal than 0.8. We use Lavenshtein distance[8] to compute the similarity between POI name.

Another rule applied to obtain check-in tweets was to utilize Instagram links found in the tweets. People publish their status on Instagram when they check-in to one place and this status links to their Twitter account. The Instagram content includes POI name without check-in word pattern. The text in the tweet will contain the Instagram link. Therefore, we extract the Instagram link in the Twitter and crawl the link to obtain a POI name where the user checks in. Then the matching rule in point ii is also applied to define the POI name. We also consider the POI opening time to validate the POI name. The example content of Instagram link can be seen in Figure 6 below.

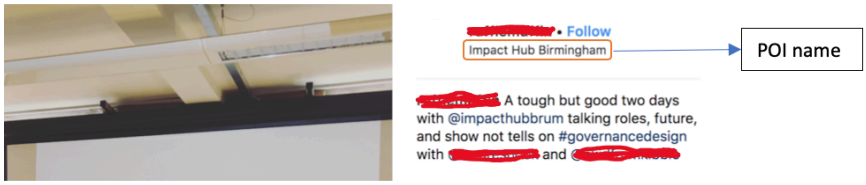


Figure 6 Example Instagram content link in a tweet

RESULTS AND DISCUSSION

In the following section, we present key findings derived from tracking and social media data. We demonstrate the capability of our method to capture rich information about human lifestyle patterns. Approaches were applied to analyse the behavioural characteristics of users in Birmingham from two perspectives: temporal pattern and spatial pattern analysis.

The tracking information was collected from 534 users in Birmingham during September 2017 to September 2018. The users were part of the population with certain characteristics related to a social-economic indicator such as income, ethnic community, medical condition or mental well-being. All tracking users were anonymous, and a single person could represent multiple users of the SETA app. Based on the framework implementation on tracking data, we found 72% (389) of users had more than 10 stay points and 50% (275) of users had between 10 and 38 stay points. Meanwhile, geotagged social media data were collected from Twitter users in Birmingham in the same period. We obtained 44,225 check-in locations in Birmingham with average 4 check-in locations per user (minimum=1, maximum=1680). Figure 7 shows the distribution of stay point or check in locations per user.

[7] https://developer.twitter.com/
[8] https://en.wikipedia.org/wiki/Levenshtein_distance

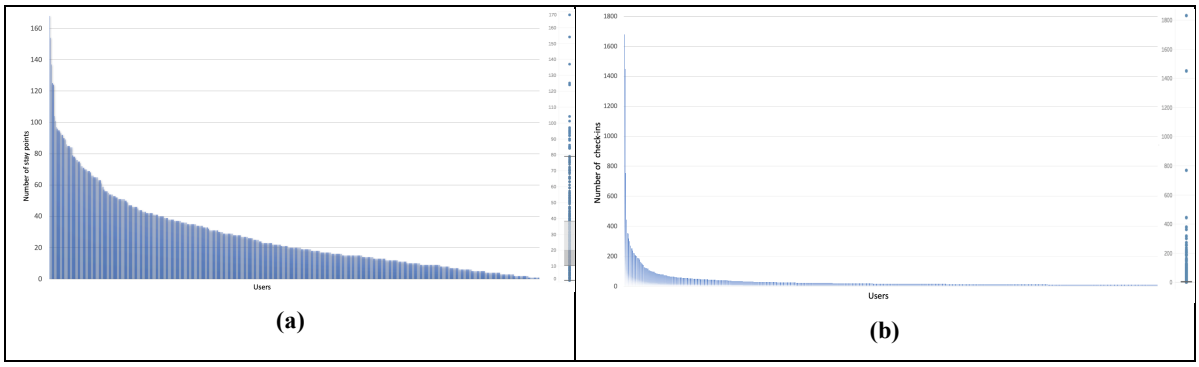


Figure 7 Number of stay point or check-in location per user. (a) tracking data (b) social media

Figure 8 shows the POI distribution for tracking and social media data. Overall, trend activity based on POI category visited by the user was very different. As can be seen, Shop & Service-related activity was the highest among user in tracking data. The remaining activities (Professional & Other places, Outdoor & Recreations, and Food related activity) follow with big different gaps. In contrast, activity patterns in social media were more uniform. Arts & Entertainment related activity was the most frequent and other activities (Food, Nightlife, Outdoor & Recreations, Professional & Other Places, Shop & Service, Travel & Transport related activity) had similar levels of popularity.

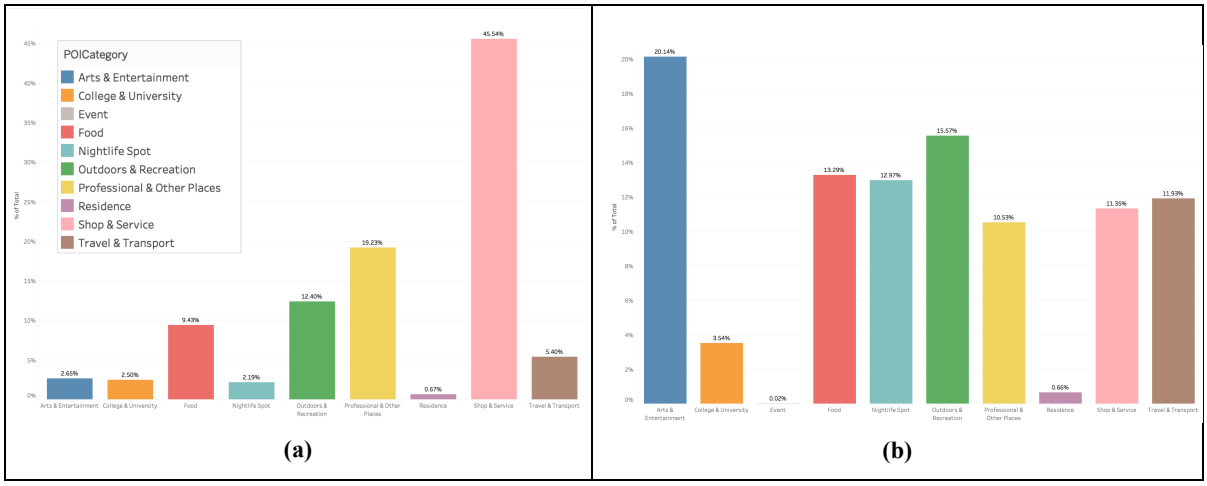


Figure 8 Statistic POI distribution (a) tracking data (b) social media

The following subsections discuss the temporal and spatial pattern results obtained from tracking and social media data.

Temporal Mobility Patterns

We extracted time (arrival time in tracking data and check-in time in social media) when users followed the activity. Figure 9 shows the number of stay points and check-ins per day. As can be seen, this pattern presents a glimpse of the active time of the user in tracking and social media data. Clearly, both users tended to follow their activities in the morning at 7 am. There is a major peak between 12 and 17 in tracking data that indicates most users followed their activity in the stay point at this time. In social media, the pattern reached a peak between 17 and 21 pm; this means that most users tended to post their activity information after office hours.

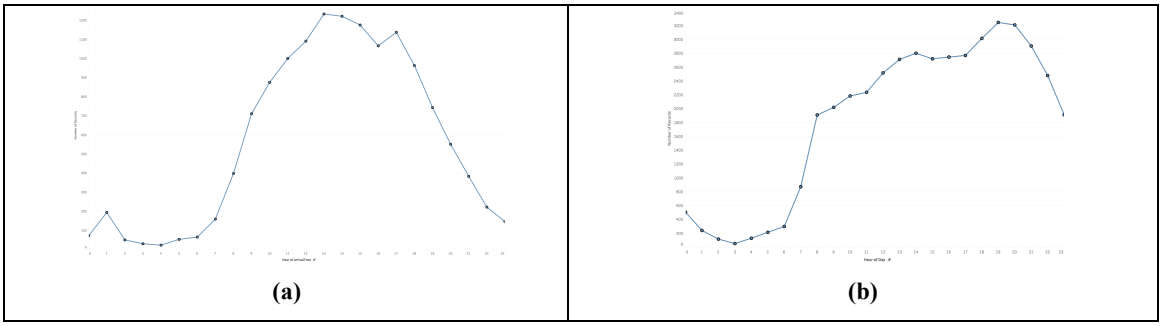
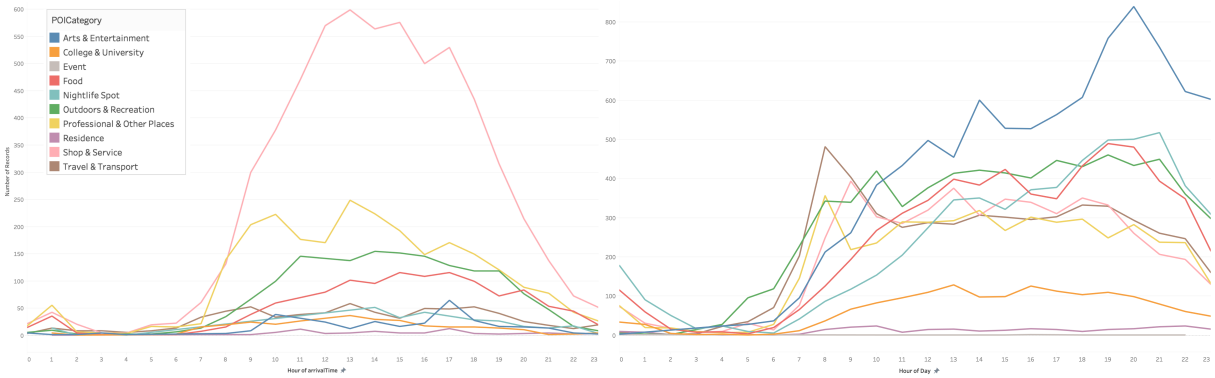


Figure 9 Time distribution of (a) tracking data and (b) social media

The temporal pattern indicates time-varying popularity where a place may be of interest to people. To reveal detailed temporal mobility regularity, we investigated the distribution of visits for POI category at different hours of the day. We aggregated the number of stay points or check-ins for each POI category in each hour of the day (see Figure 10). The weekly pattern of these visits was also examined and can be seen in Figure 11.

We observed that activity purpose had a pronounced impact on the time of activities. For instance, we can see that food-related activities in these two datasets had three distinct peaks around noon (12-13 pm), evening (15 pm) and early night (17-19 pm). Nightlife activities were more popular during afternoons and nights and peaked around night (21 pm) as these visits mostly constituted going to bars and nightclubs (even though, nightlife activity was not common in tracking data). Furthermore, we can see that activity related to professional places was increasing significantly in the morning (after 7 am) and remained steady between 8 am - 17 pm. This shows that this activity was mostly in a working place or school. Similarly, outdoor and recreation-related activity also remained constant between 6 am - 19 pm.

As pointed out above, shop and service-related activities were more dominant for tracking users (Figure 10(a)), increasing significantly in the morning (9 am), peaking around afternoon (13 pm), and dropping steadily until 17 pm. This pattern decreased dramatically after 17 pm. Using semantic stay point, we identified most of those places were the Shopping centre, Shopping Park, or supermarkets. This indicates that most users bought their supplies, such as food, clothing, etc. at this time. Most of the users also went to eat at food outlets or fast food restaurants between 13 and 17 pm. Professional & other place related activities rose sharply in the morning - at 8 am (going to work), reached a peak at 13 pm (back to work places after rest breaks) and fell gradually around 18 pm. Furthermore, the pattern shows that more people visited parks, leisure or sports centres around 11 am - 17 pm. Nightlife and Art & Entertainment related activities were less popular in tracking data at only 4.8% of all activity.

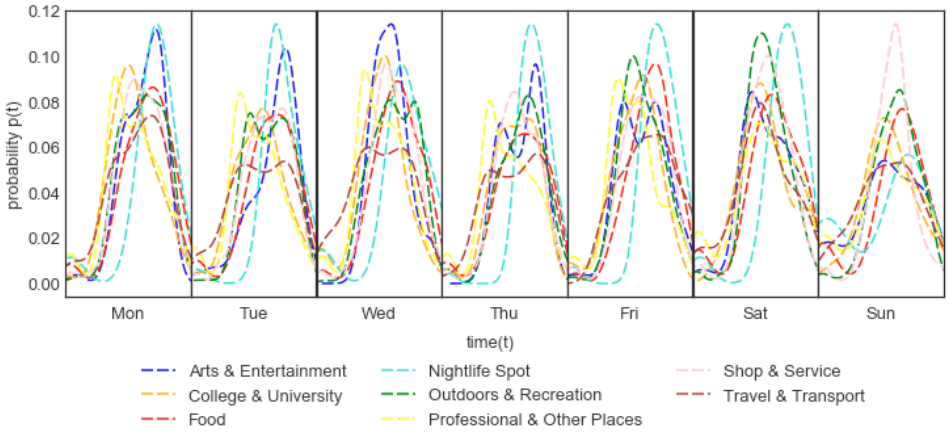


(a) **(b)**

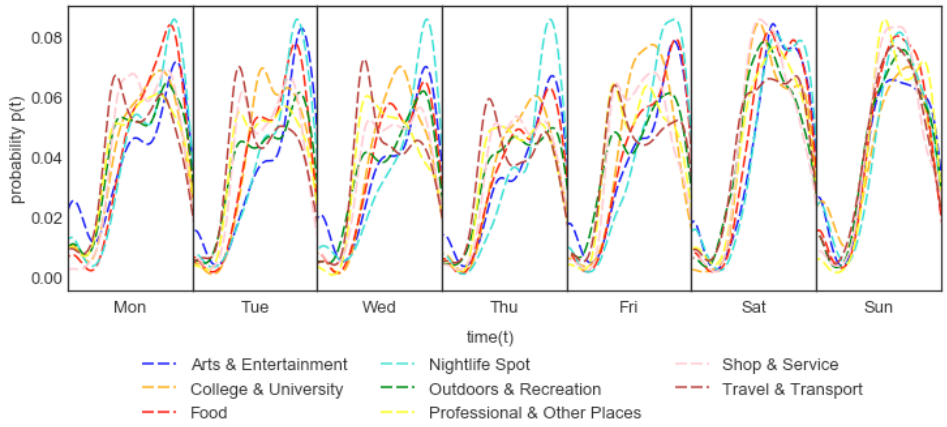
Figure 10 POI popularity over 24 hours in a day. (a) tracking data (b) social media

Figure 10(b) shows the activity patterns in social media were more comprehensive than tracking data. More people visited Art and Entertainment places around 14 pm and between 17 - 22 pm (after office hours) as these activities mostly involved attending an event in such places (Birmingham arena, The Genting Arena, O2 Academy, etc.). Shop and service-related activities fluctuated between 8 am - 19 pm and peaked around morning (9 am), and noon (13 pm). This activity was mainly conducted in food markets, shopping plaza, or shopping mall and some service places. Travel and transport activity reached a peak at 8 am when people were going to work, remained steady between 11 am and 18 pm, and decreased gradually after 18 pm when people finished working. Furthermore, most people bought food (eat and drink) in a restaurant or cafe at lunch (13 pm) and dinner time (19 pm - 20 pm).

Figure 11 shows the stay point or POI check-in density for every day in tracking and social media data. As can be seen, art and entertainment, and nightlife related activity was more popular on weekdays, and shopping activity was more dominant at the weekend. In social media, weekly patterns suggest that art and entertainment and nightlife related activity was dominant on weekdays after 12 pm, whereas shopping and recreation trips were predominant at the weekends. Users in social media also tended to post their activities from travel and transport places in the morning on weekdays. Similarly, tracking users visited art and entertainment and nightlife places on weekdays. Most users followed shopping & service, outdoors and recreation related activities at the weekend.



(a)



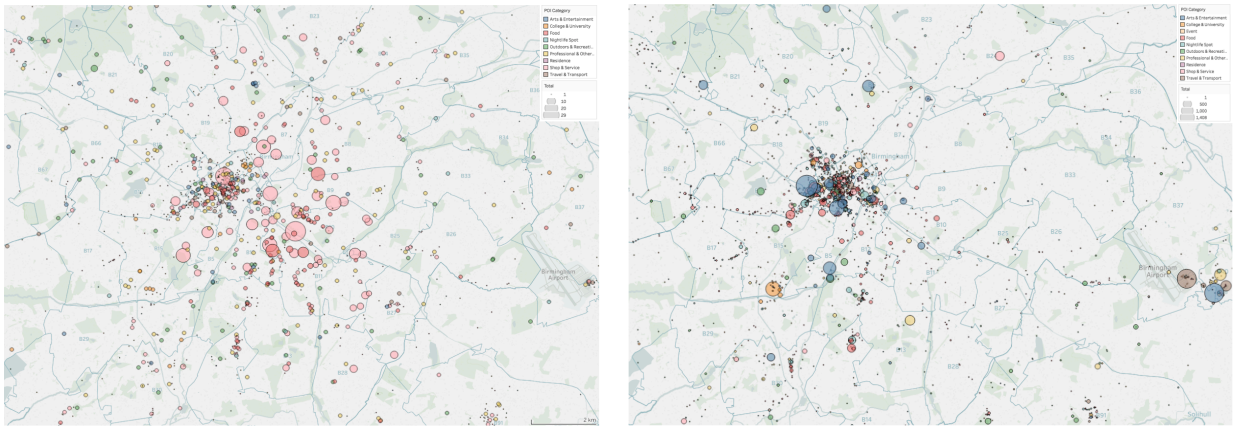
(b)

Figure 11 Temporal POI Check-in densities every day for a) tracking data b) social media data

Based on the temporal pattern results explained above, we can see our method has the capacity to capture detailed lifestyle patterns from tracking data and social media. Different patterns in tracking and social media data were obtained related to when users followed the activity and the type of POI visited. Clearly, most of the activity in tracking data was carried out between 9 am - 17 pm. During this period, the trend of activities (except shopping and service-related activity) showed small changes. In contrast, most users in social media tended to post their activity at a particular time: in the morning when they were starting an activity, during their lunch break and after working hours. Related to type of POI, most users in tracking data followed a routine activity by visiting the same place of POI several times (shopping in a specific kind of supermarket, etc.). Social media users posted their activity when attending an entertainment event, shopping in the plaza or mall, or eating in a restaurant. The POIs visited by user in social media were sparser than in tracking data.

Spatial Distribution of Popular Places

The current section demonstrates that our method can be used to visualise popular POIs in the city. The popular places visited by the citizen from tracking and social media data are generated by counting the total number of stay points or check-ins for each POI. The density for each region corresponds to the number of stay points or check-ins to that POI. Figure 12 and 13 show a visualisation of the spatial distribution of stay points and check-ins in the Birmingham area. The sizes of the circle indicate the number of stay points or check-ins at the POI.



(a) (b)

Figure 12 Spatial POI Check-in densities every day for a) tracking data b) social media data

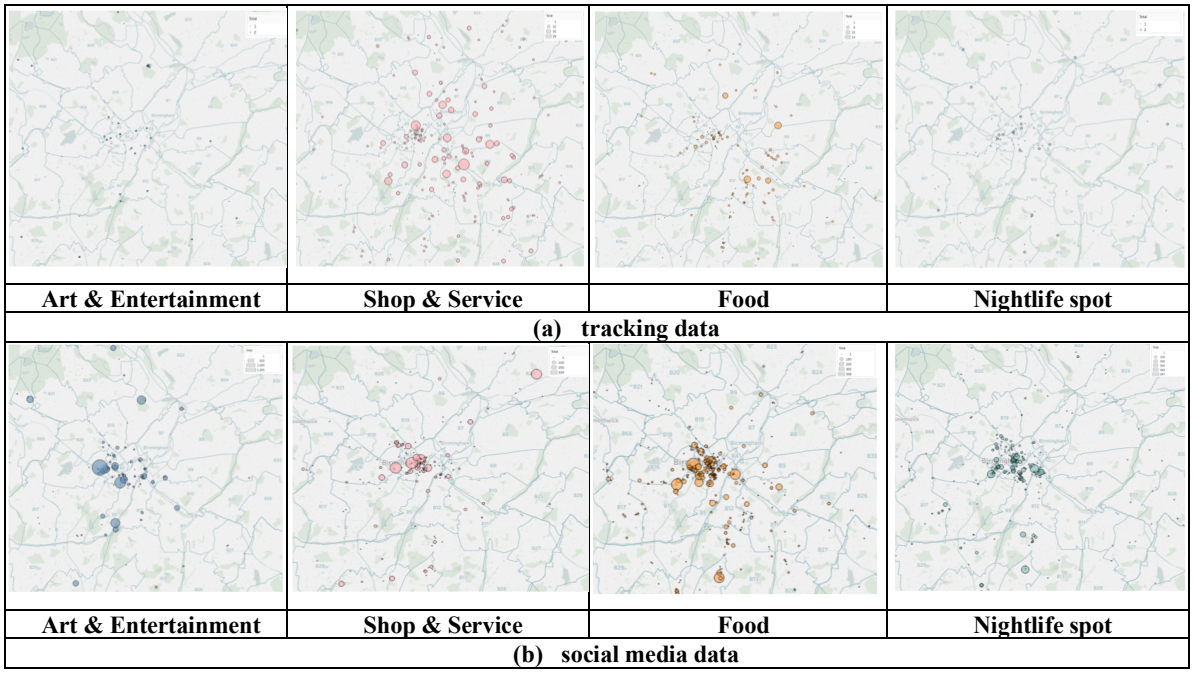


Figure 13 Spatial POI Check-in density for some POI Categories

As shown in Figures 12 and 13, popular places differed depend on activity purpose (POI category). The most active POI in tracking data was shopping and service places and few places had very high numbers of people who usually visited for eating, entertainment and nightlife purposes. Whereas in social media, other places such as art and entertainment, food and nightlife spots were also active POIs in the city. Clearly, there were more check-ins for eating, entertainment and nightlife activity in social media than in the tracking data.

Furthermore, stay point and check-in distributions look different for various activities. For example, the distribution of stay points for shopping and service-related activity and other (art and entertainment, food, nightlife) related activity look very different. Distribution of shopping and service-related activity in tracking data spread (scattered) in the city, where those places were shopping centres or supermarkets. Probably, people shopped in these particular places according to the proximity of the POI to their home. While, the distribution of activity from social media was more concentrated in the city centre, it was sparser and spread among different types of POI.

The analysis above highlights the significant differences between patterns in tracking and social media data. Users in social media were random (more variable) since data collected from all active users on Twitter who posted tweets in the Birmingham City area. Furthermore, social media usually contain features of sparsity and uncertainty. Spatial-temporal data provided by geo-located tweets are typically sparse due to the high interval

between two consecutive tweets in the spatial dimension. Activity found in social media is often occasional and discontinuous. Users in social media tend to share their geotagged tweets related to an interesting event, exciting moment or express their experience when they are in certain places with/without other people.

In contrast, tracking data provide regular/routine detailed activity conducted in daily life. Therefore, some places were visited several times. Shopping activity was the dominant activity where most places visited by the user were the shopping centre, shopping park, or supermarket. Users in tracking data were not random. As explained above, the apps were used by part of the population in the city with a specific social economy or medical condition characteristics. Therefore, we did not have the largest number of users in the parts of the city where they were the largest part of the population; there does not seem to be a close correlation between tracking user distribution and population size. Nevertheless, the results show that we are able to track citizens with some characteristics, capture the rich context of human lifestyle, and model their lifestyle patterns based on visited stay points. The lifestyle patterns show the power of analysis that clearly explains that these citizens are a part of the population in the city.

Understanding daily lifestyle patterns of the population enables decision makers to understand citizen needs, such as where and when they get supplies (e.g. food), and how the different parts of the city are connected. Monitoring these patterns allows us to understand, learn, and gauge the level of disruption after an event, as it is possible to check habit deviation from normal conditions post-event.

CONCLUSION

In this paper, we have presented a framework to build an understanding of mobility lifestyle patterns from tracking data. Even though the method has not yet been used during a crisis, our result shows that the stay point annotation from tracking data and POI check-in from social media can effectively explain daily life patterns in the city especially related to the usage of public infrastructure, such as shopping places, food, nightlife, etc. This detailed information is very useful for monitoring and learning how the population behaves (deviation of habit) before or after a crisis or gauging the level of disruption after an event.

We note several limitations within our study. The tracking data used are constructed from parts of the population in a specific category in the city and not incorporate data from some representative portions of the population (i.e., people who do not own mobile devices or do not register for a GPS service cannot be incorporated into this study). Therefore, the patterns found are related to certain types of people more likely to have a specific condition (related to social economic indicator). However, we are confident that the tracking data, which offer movement behaviour for the approximately 534 people included in the database, are reflective of part of the population lifestyle patterns. Furthermore, ambiguities in defining home and working place (to distinguish people having fun or working in pubs during the night; people who live and work in the same building (ground and 1st floor) are concerned to be future work to improve our algorithm. The third limitation of our study is the context of mobility only considered the stay points. Therefore, we are concerned to improve our method in future work, especially related to the number of the population examined and analysing the changing patterns of mobility regarding other semantics, such as large events or environmental conditions.

ACKNOWLEDGMENTS

The activity has been generously funded by a number of bodies: the European Commission as part of the SETA European Project (contract no. 688082); in England through funds from the national health system; from the University of Sheffield; and the National Centre for Sports and Exercise Medicine (NCSEM)

The authors would like to express their gratitude to the Indonesia Endowment Fund for Education for the research dissertation grant.

REFERENCES

Cho, E., Myers, S. A., & Leskovec, J. (2011). Friendship and mobility: user movement in location-based social networks. *17th ACM SIGKDD international conference on Knowledge discovery and data mining.* San Diego, California.

Ciravegna, F., Gao, J., Ingram, C., Ireson, N., Lafranchi, V., & Simanjuntak, H. (2018). Mapping Mobility to Support Crisis Management. *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management*, (pp. 305-316). Rochester.

de Graaf, V., de By, R. A., & van Keulen, M. (2016). Automated semantic trajectory annotation with indoor point-of-interest visits in urban areas. *Proceedings of the 31st Annual ACM Symposium on Applied Computing* (pp. 552-559). Pisa, Italy: ACM.

Ester, M., Kriegel, H.-P., Sander, J., & Xu, X. (1996, August). A density-based algorithm for discovering clusters in large spatial databases with noise. *Proceedings of the Second International Conference on Knowledge Discovery and Data Mining. 96*, pp. 226-231. Portland: AAAI Press.

Fan, Z., Song, X., Xia, T., Jiang, R., Shibasaki, R., & Sakuramachi, R. (2018). Online Deep Ensemble Learning for Predicting Citywide Human Mobility. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2*(3), 105.

Hong, L., Fu, C., Torrens, P., & Frias-Martinez, V. (2017). Understanding Citizens' and Local Governments' Digital Communications During Natural Disasters: The Case of Snowstorms. *Proceedings of the 2017 ACM on Web Science Conference* (pp. 141-150). New York: ACM.

Hong, L., Lee, M., Mashhadi, A., & Frias-Martinez, V. (2018). Towards Understanding Communication Behavior Changes During Floods Using Cell Phone Data. *International Conference on Social Informatics* (pp. 97-107). Springer, Cham.

Kumar, D., & Ukkusuri, S. V. (2018). Utilizing Geo-tagged Tweets to understand Evacuation Dynamics during Emergencies: A case study of Hurricane Sandy. *WWW '18 Companion Proceedings of the The Web Conference*, (pp. 1613-1620). Lyon.

Li, Q., Zheng, Y., Xie, X., Chen, Y., Liu, W., & Ma, W.-Y. (2008). Mining user similarity based on location history. *Proceedings of the 16th ACM SIGSPATIAL international conference on Advances in geographic information systems*, (p. 34). Irvine, California.

Ludwig, T., Kotthaus, C., Reuter, C., Dongen, S. v., & Pipek, V. (2017). Situated crowdsourcing during disasters: Managing the task s ofspontaneous volunteers through public displays. *International Journal of Human-Computer Studies, 102*, 103-121.

Sila-Nowicka, K., Vandrol, J., Oshan, T., Long, J. A., Demšar, U., & Fotheringham, A. S. (2016). Analysis of human mobility patterns from GPS trajectories and contextual information. *International Journal of Geographical Information Science, 30*(5), 881-906.

Song, X., Zhang, Q., Sekimoto, Y., Shibasaki, R., Yuan, N. J., & Xie, X. (2015). A Simulator of Human Emergency Mobility following Disasters: Knowledge Transfer from Big Disaster Data. *AAAI*, (pp. 730-736).

Song, X., Zhang, Q., Sekimoto, Y., Shibasaki, R., Yuan, N. J., & Xie, X. (2017, January). Prediction and Simulation of Human Mobility Following Natural Disasters. *ACM Transactions on Intelligent Systems and Technology (TIST), 8*(2), 29.

Vu, H. Q., Li, G., Law, R., & Zhang, Y. (2017, August 11). Tourist Activity Analysis by Leveraging Mobile Social Media Data. *Journal of Travel Research, 57*(7), 883-898.

Wang, Q., & Taylor, E. J. (2016). Patterns and Limitations of Urban Human Mobility Resilience under the Influence of Multiple Types of Natural Disaster. *PLOS ONE, 11*(1), https://doi.org/10.1371/journal.pone.0147299.

Wu, F., & Li, Z. (2016). Where Did You Go: Personalized Annotation of Mobility Records. *Proceedings of the 25th ACM International on Conference on Information and Knowledge Management* (pp. 589-598). Indianapolis: ACM.

Xiao, Y., Huang, Q., & Wu, K. (2015). Understanding social media data for disaster management. *Natural Hazards, 79*(3), 1663–1679.

Yan, C., Xiao, M., Ding, X., Tian, W., Zhai, Y., Chen, J., . . . Ye, X. (2018, January 12). Exploring human mobility patterns using geo-tagged social media data at the group level. *Journal of Spatial Science*, 1-18.

Yuan, N. J., Zheng, Y., & Xie, X. (2017). Discovering Functional Zones in a City Using Human Movements and Points of Interest. *Spatial Analysis and Location Modeling in Urban and Regional Systems. Advances in Geographic Information Science*, 33-62.

Sorting the good from the bad smartphone applications to alert residents facing disasters – Experiments in France

Esteban Bopp

UMR ESPACE 7300 CNRS, Département de Géographie, Université d'Avignon

esteban.bopp@univ-avignon.fr

Johnny Douvinet

UMR ESPACE 7300 CNRS, Département de Géographie, Université d'Avignon

johnny.douvinet@univ-avignon.fr

Damien Serre

Ecosystèmes Insulaires Océaniens, UMR 241, Université de la Polynésie Française

damien.serre@upf.pf

ABSTRACT

The number of smartphone applications to alert and inform the population in a risk situation in France is too large and these solutions are still unknow by the population. This study proposes an evaluation protocol based on various indicators, which take into account the capacity of the applications to send a targeted alert, their attractiveness, the ability of individuals to emit information and number of hazards considered. The results obtained on 50 applications deployed in France show that very few of them meet the objectives of the alert, in the sense defined by civil security, because of a single-risk approach, a unique sense of communication, and the low acceptance of these solutions by citizens.

Keywords

Alert, smartphone application, major risks**.**

INTRODUCTION

The combination of unpredictable hazards with climate change and increased exposure of populations makes territory more and more vulnerable (Kelman, 2011; Vinet *et al.,* 2017). The physical extent of the disaster makes it very hard for residents or affected human to react in timely fashion. Significant research and development efforts are required to create or improve systems to predict natural disasters, and to efficiently alert humans at the earliest possible time through different communication channels (Carley *et al.*, 2015; Choy *et al.*, 2016; Lindsay, 2011; Matveeva, 2006). The purpose of the alert is to warn citizens against a threat, a danger (Linardi, 2016) so that

citizens can make decision and take action for safety (Daupras *et al*., 2015; Sorensen, 2000). Due to its shorter temporality, the term "alert" differs from the term "warning" which takes into account forecasting and hazard monitoring. Thus, the alerting tools goals are: 1) spreading alert messages to citizens to inform them on the nature of the danger and its intensity; 2) advise citizens about actions to undertake.

In this paper, we focus on a specific alerting tool, smartphones applications, in order to measure the potential effectiveness of these solutions to play a role during alerts. Such solutions represent considerable scientific interest in the way this tool impacts our environment (Barr *et al*., 2015; Brownlee and Liang, 2011), our economy (Poushter, 2016) and our displacements (Adoue, 2015): in 2015, 3.7 billion people have a smartphone in the world. During a crisis, smartphone apps change the way in which people interact (Goodchild, 2007 ; Laurila, 2013 ; Slingsby *et al*., 2013), especially during alerts (Chatzimilioudis *et al.,* 2011 ; De Longeville *et al*., 2010 ; Douvinet *et al.,* 2017 et 2018 ; Fajardo et Oppus, 2009 ; Kouadio, 2016). Mostly, smartphone applications have the potential to improve the accuracy and timeliness of information over events in progress, to improve planning and alerts and communications between institutions and humans (Slingsby *et al.,* 2013): 1) they can locate citizens in real-time and communicate with them; 2) they can generate a "two-ways" interaction between users and decision centers, in an ascending logic (Goodchild, 2007); 3) smartphones messages and signals are moreover more understandable than sound signals (alarms) or shorter signs.

The development of smartphone applications to alert in the case of disasters has greatly increased since the years 2010 (namely after the seismic damage that has occurred in Haïti or after floods in Brisbane, Australia). In France, these tools are gradually being used since 2014 (Kouadio, 2016; Douvinet *et al.*, 2017). French government has launched its own app dedicated to alerts at the national level in June 2016, especially due to the increasing risk of terrorism since 2015. SAIP® app (*Alert and Information System for the Population*) has nonetheless been abandoned in May 2018, due to several missed and false alerts. In parallel, specific alert applications have been displayed since 2015 at the local level (in several municipalities like Nîmes, Nice, Hyères, Athis-Mons, etc.). In addition, private companies have massively engaged in the development of these solutions on an international scale (operating in the world, like ELERT®, Qwidam®, Signalert®, WeatherAlert®, etc.) in order to cover all hazards and probable related dangers. In many cases, applications results from public-private partnerships and need significant human and economic resources, and a major political decision to develop them.

In France, the massive creation of smartphone applications cause a high competitive logic between stakeholders involved, and a strong confusion for citizens who struggle to find their way in the face of the diversity of solutions. All available solutions present variable criteria and characteristics, especially in terms of the communication mode, the price, the spatial coverture, etc. Thus, it remains difficult for citizens, stakeholders or scientists, to know the best solutions. This has the consequence of increasing the gap between citizens who want efficient and operational emergency applications, and institutions that are reluctant to invest digital tools (Vogel, 2017).

In the scientific literature, most of the studies are focused on the technical capabilities of applications (Fragkiadakis *et al*., 2011; Chatzimilioudis *et al.,* 2011) rather than how the content is perceived by the public (Lindsay, 2011). Furthermore, the social appropriation of smartphone applications is still poorly and insufficiently documented (Bopp *et al*., 2019; Douvinet, 2018). Thus, comparing several smartphone applications available in France since few years, this article supplies two contributions. First, we experienced a retrieval method to classify and hierarchize the "good from the bad smartphone applications" proposing to alert users to natural risks. A "good application" simultaneously corresponds to the need to attract attention and deliver an instructional message (DGSCGC, 2013). The method has been designed to "put oneself in the shoes of a future user", to go beyond standard indicators that are limited to measures the internal efficiency of applications and are insufficient to explore how humans play a major role during crises. Second, we wish to select the applications with the high scores and discuss the opportunity to develop them in France. Such a choice might impulse major political changes, as sirens remain the priority for the French government in charge of alerting the population facing disasters since the end of the 2nd World War (Vogel, 2017; Douvinet, 2018).

The paper is organized as follows. Section 2 presents the data collection and the main elements used to implement the evaluation. Section 3 presents the obtained results through the evaluation of 50 applications displayed in

France. In section 4 and 5, the benefits and limits of the evaluation tools as well as the results are discussed, and conclusions are drawn in Section 6.

METHODS AND DATA COLLECTION

The basic elements needed for the evaluation are explained here and a functional description of each indicator is introduced. Applications have been uploaded in March 2018 *via* specialized search engines (Google Play®, Play Store®) using keywords: alert, risk, SOS, warning, disasters, hazards, etc. Every application has been rigorously tested and only applications allowing the sending of an alert to a risk have been retained.

Our evaluation method is first based on four major indicators identified using the scientific literature and experiences feedback. A "good" smartphone application for the alert must be regarded according to (1) its potential to alert and inform the user in case of disasters (with the postulate that such information is relevant); (2) its potential to allow interactivity between users and the decision center; (3) its potential to take into account all the existing hazards on the France territory (to permit adaptation to various situations); (4) its potential to be attractive to prevent users from deleting them.

The potential of alerting and informing users

French authorities define the alert as a signal intended to warn citizens of a danger, imminent or in the process of producing its effects, which may affect their physical integrity and requires the adoption of a reflexive backup behavior (DGSCGC, 2013). Then, the alert process is expected to: 1) be intrusive, with a clear and short message that breaks with usual information; 2) be targeted, by defining an alert zone; 3) trigger an immediate response to exposed populations (Douvinet, 2018). In this sense, a good application needs to support people in the affected area to take the correct actions (Kouadio, 2016). First, applications can send a push notification, an interruptive message that appears on the screens even if the application is closed, that corresponds to the interruptive character and intrusive expected alerts (Tang *et al*., 2013). Secondly, applications allow geolocation of users. Precious during crisis management, the "location-based mobile telephony services" (Aloudat *et al*., 2014) allows the sending of a targeted alert to citizens located in the potential area of the hazard, provided that they agree to communicate their position. Smartphone applications have other capabilities in improving the dissemination of alert messages and their understanding thanks to hazards visualization in real time on map interfaces or the possibility to relay alerts through Social Medias.

The potential of interactivity

Humans have a better perception of risks when they have been integrated in the design and preventive phase (Gaillard *et al.,* 2010; Garcia, 2012). Citizens are empowered to observe and transmit data through the Internet, connected objects or crowdmapping (Becker and Bendett, 2015; Riccardi, 2016; Ziemke, 2012). In addition, decision centers need to quickly acquire accurate information in times of crisis (Villela *et al*., 2018). A good smartphone application may allow citizens to interact with warning systems (Budhatoki *et al*., 2010; Horita *et al*., 2013; Okolloh, 2009). Interactive applications allow users to detect all "weak signals" revealing disasters in progress (Kouadio, 2016). In this sense, a single "top-down" broadcast communication mode, coming from the decision center to users, is less relevant than a "bottom-up" mode of dissemination from the user to the decision center, or than a "peer-to-peer" mode enabled by a mesh network deployment.

The multi-hazard dimension

The multi-hazard concept refers to the fact that different hazards may threaten the same element and that one event may trigger others (Liu *et al.,* 2017, Nadim and Liu, 2013). Consequently, a smartphone application developed to alert people facing to a single hazard is limited. In France, 12 major risks are identified and defined by the authorities as "the threat to human people and his direct environment (…) whose gravity is such that society is absolutely overwhelmed by the immensity of disaster" (DGSCGC, 2013). Eight natural risks exist (flood, earthquake, volcanic eruption, movement of land, avalanche, forest fires, cyclone and storm) and the other four

are anthropogenic risks (nuclear risk, industrial risk, transport of hazardous materials, dam failure). Although the distribution of hazards is very heterogeneous in France, an application developed throughout France must take into account these 12 major risks. Thus, the app will be adapted to various situations that users can face. We don't take into account here cascading effects between hazards considering that humans need to be alerted whatever the spatial distribution of hazards.

The potential of attractiveness

The attractiveness of an application is a key parameter to its general use. The user is able to determine (during its first use) if one application is useful or not for him (Adoue, 2015). If two applications present similar functionality, the quantity and quality of information provided and its ergonomic aspect are determinant in the user choice (Adoue, 2015). The color choice is particularly decisive in the user's appreciation of the app (Weinclich, 2014). Some researchers then aim to ensure compatibility between the characteristics of users, the technical products, and the systems in order to facilitate their use (Barcenilla and Bastien, 2009). Attractiveness is a fuzzy parameter involving user experiences on the product. Poorly studied in the scientific field, the user experience requires evaluating both pragmatic qualities (usefulness, usability) and hedonic qualities (stimulation, identification perceived by users on the product (Hassenzahl, 2004; Väätäjä *et al.,* 2009). In our research, without being able to assess such user qualities, it is only possible to look at the pragmatic qualities of applications. The usefulness of apps can be assessed through various offered functionalities: interactive cartography and usefulness of information (such as real-time traffic or weather, presence of information and instructions on risk, etc). The usability can also be checked with the presence or absence of advertising and detected bugs. Price of apps is also a parameter of this indicator.

How to convert qualitative criteria into quantified indexes?

Figure 1 details the methodology used to evaluate applications. The four indicators are defined by a certain number of settings ranging from 0 to 1 and weighted according to their importance.

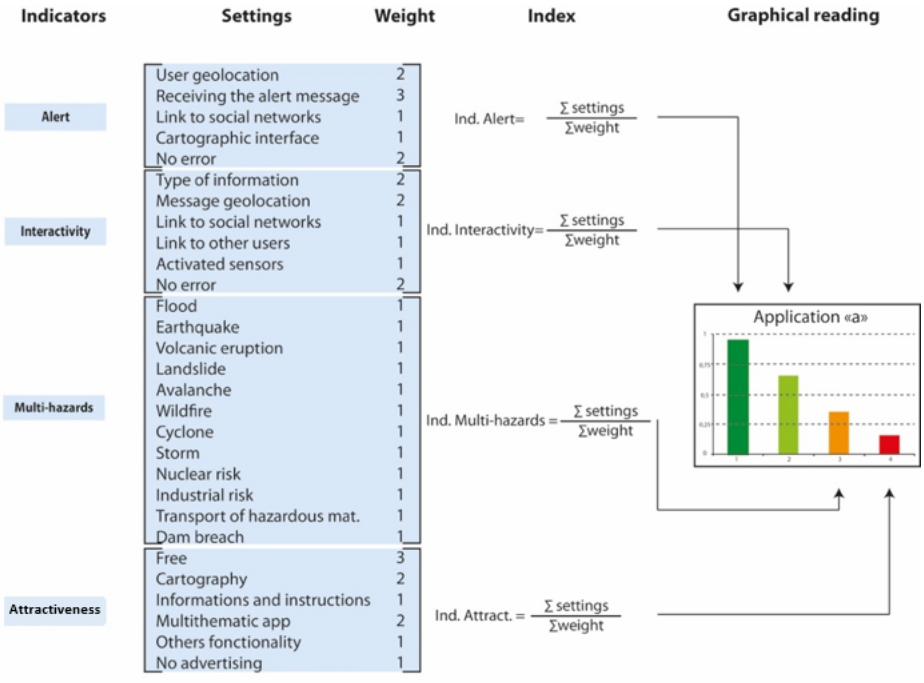


Figure 1. Indicators and selected settings to define them.

With this methodology, each criterion can be measured in the same units, and differences in values on different criteria are comparable and can be offset (Serre, 2005). Settings were weighted with a simplified point rating system (1, 2 or 3), according to the literature review. Therefore, such a method emphasizes the importance of

application functionality in the field of alerts (Shan and Lai, 2015, Shih *et al*., 2013), including the issuance of information by users (Chatzimilioudis *et al*., 2012) and the attractiveness of applications (Weinlich *et al*., 2014). Finally, the sum of the settings was aggregated and ranged from 0 to 1 to propose an index per indicator. The four indexes obtained make the classification easier between applications. One graph finally presents the results obtained for all indicators, to avoid an excessive loss of information with initial setting an increasing color refers to the obtained values. This method fits directly into the main principles of the *Multi-criteria Hierarchization Methods* (MHM), invented by Saaty (1984) and which can now be distinguished according to the objectives and points of view (Maystre *et al*., 1994).

RESULTS

This method was first tested on four applications and experimented on fifty applications dedicated to alerting humans in case of disasters. The selected sample renders the compilation of a wide variety of functional applications available in France possible.

Detailed results for each indicator

Surprisingly, the attractiveness globally performing well for all applications, whereas the alert, multi-hazards dimension or interactivity indicators are heterogeneous (Table 1 and Figure 2). The high average (0.64) and the minimal variation for attractiveness (0.45) are explained by the fact that 35 applications are free, 34 allow the visualization of a disaster on maps and 23 complete alert messages with behavior guidelines and information. Only 11 free applications contain advertising and some apps have features to directly contact relief or reassure loved ones. The calculated average for the alert indicator (0.58) and dispersion of values are explained by the fact that geolocation and reception of the message have been weighted: 36 applications allow the geolocation of users, including 32 automatically, and 25 use the push notification. 22 applications allow interactions with other social media and 36 are related to a mapping of a disaster in real time. 36 do not present any error or malfunctions during the test phase, whereas the quality of reception disturbs the performance of others (14). The calculated average for interactivity (0.29) is weakest, and highest standard variations are explained by the fact that only 20 applications allow current relations between users and decision centers. Some of them (17) activate at least one predefined sensor (digital camera or voice recorder), but only 7 allow comments within social media and only 11 allow users to exchange information with other users. But 18 applications present malfunctions in the information sending test phase, including 13 applications where these malfunctions have a strong impact on the quality of information sending. The multi-hazard is also discussed: 23 applications are multi-hazard but only 11 take into account all the hazards related to a major disaster in France. 14 tested applications focus on a single hazard (mainly in the case of earthquakes or floods). 7 applications do not take into account any of the 12 hazards selected in this study. Most solutions (Table 2) consider natural disasters (79.4%) and rather than anthropogenic disasters (20.6%).

Table 1. Detailed results for each indicator.

	Alert	Interactivity	Multi-hazard	Attractiveness
Average	0.58	0.29	0.64	0.64
Mode	0.56	0.00	0.08	0.60
Decile 1	0.00	0.00	0.00	0.45
Decile 9	0.89	0.78	1.00	0.90

Table 2. Hazard taken into account by the applications.

Type of disasters	Number of app	Type of disaster	Number of apps
Flood	30	Snow avalanche	19
Cyclone	25	Volcanic eruption	18
Storm	24	Landslide	16
Earthquake	24	Industrial risk	12
Wildfire	21	Dam break	11

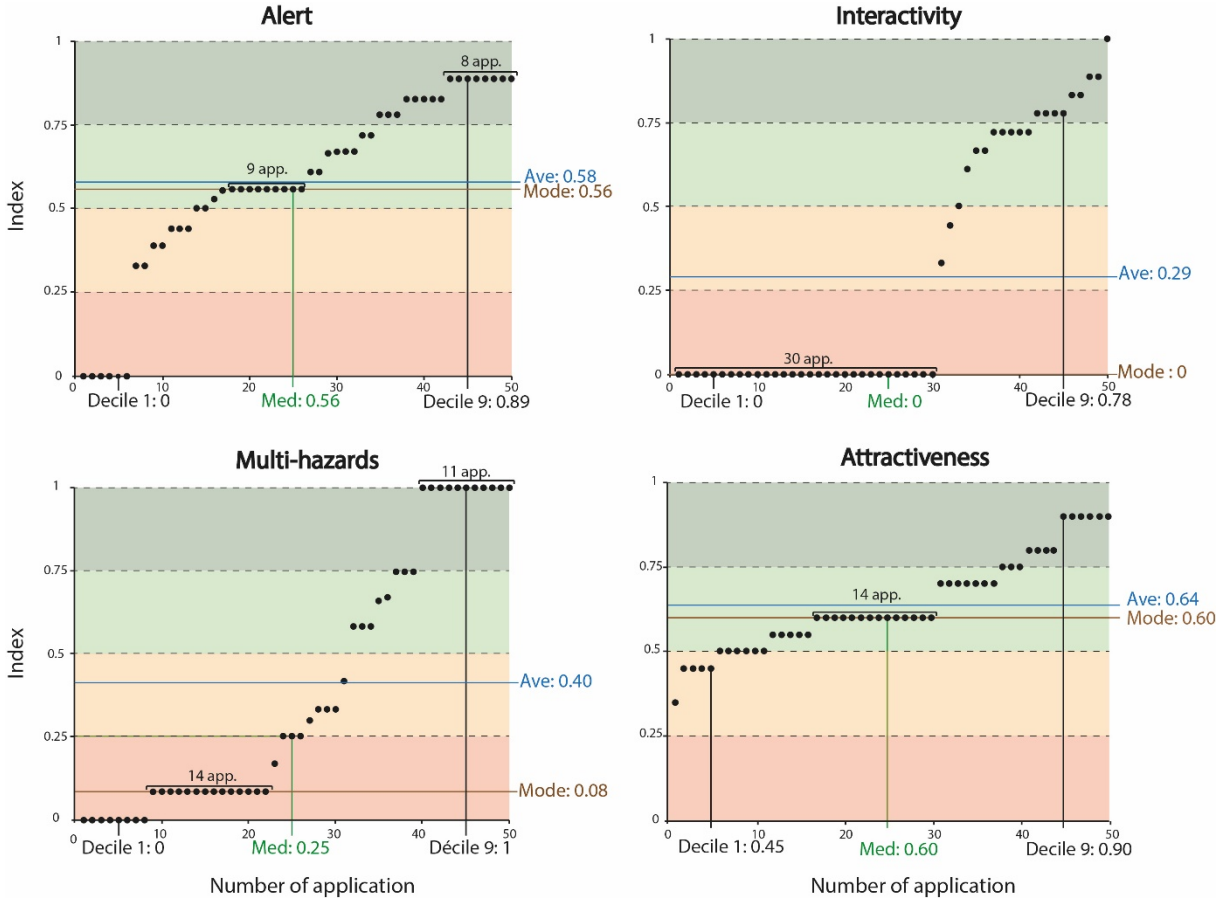


Figure 2. Ranking of results for the four indicators.

Global overview

The overall evaluation (Figure 3) provides additional lessons. Only 4 applications have their 4 indexes greater than 0.50 whereas 34 apps have at least one zero index. 3 applications present a global index greater than 3.00, while 28 applications have a global index of less than 2.00. Consequently, a few applications are really considered effective at alerting humans, but their number appears limited. By classifying these 50 applications, we obtained a curve with regular ascendancy. The standard deviation equals 0.35 and deciles 1 and 9 are not in extreme values (respectively 1.14 and 2.69). Applications are mostly private (34 applications) and companies aim at democratizing their own products as widely as possible (Douvinet *et al.,* 2017). Hence a high prevalence of applications that can be used on a global or continental scale: over the 25 displayed at global or continental levels, 21 are managed by private entities (Tables 3 and 4).

Table 3. Nature of hosting structures for applications.

Managing structures	Number of app	Global index
Institutional apps	16	2.01
Governement	*4*	*2.26*
Local	*5*	*1.91*
Non-governemental organisations	*7*	*1.86*
Private companies	34	1.87

Table 4. Type of spatial deployment for the 50 studied applications.

Spatial coverture	Number of app	Global index
Local level	5	2.09
National level	20	1.72
Continental level	9	2.05
In the world	16	1.70

The 5 applications obtaining the best results are shown in Table 5. These applications are multi-hazard, participative, and so present a good potential to be an effective alert tool for humans in the case of a disaster. Some others have a good evaluation for only one indicator, but insufficiently take into account the complexity of the alert process and its interactivity. The interactions between all stakeholders is therefore crucial as it currently leads to a certain reverse hierarchy of information: the latter, until this point confined in top-down stream (only going from the authorities towards the population) must now take into account bottom up and horizontal streams, ranging from the users to the authorities or between users (Coyle *et al.,* 2009; Douvinet, 2018).

Table 5. Values obtained for the five best applications.

Tested applications	Alert index	Interactivity index	Multi-hazard index	Attractiveness index	Global index
Elert®	0.89	1.00	1	0,6	3,49
Vialert®	0.67	0,72	1	0,7	3,09
Signalert Pro ®	0.89	0,89	0,75	0,5	3,03
Qwidam ®	0.61	0,70	1	0,55	2,88
HelpMe ®	0.44	0,89	1	0,5	2,83

Alerte inondation
0.78
Alerta Huracan
1.01
Asteroid Alert
1.03
Athis -Mons
1.04
FloodWatch
1.14
Quake Alert
1.22
Flood Near Me NWS
1.24
Emergency Services: Europe
1.27
Alerte orage Meteoplaza
1.31
Alerte pluie UE
1.32
Alerte pluie Meteoplaza
1.33
My Earthquake Alert
1.36
La croix rouge
1.38
AlertsPro
1.40
Earthquake Alert
1.47
Natural Disaster Monitor
1.49
Riskalertes
1.51
CodeRED
1.52
Aviva risque météo
1.52
Météo-Languedoc
1.64
eQuake
1.77
Tornado - American Red Cross
1.79
Hazard Alert
1.85
Wildfire Alert
1.87
White-risk
1.89
SAIP
1.92
Inondation et catastrophe
1.96
Flood Alert live England Wales
1.97
Huricane - American Red Cross
2.04
Spotlight
2.04
Signalert
2.08
Alerte citoyen
2.10
Waze
2.13
Disaster Ready
2.20
Séisme+
2.20
Disaster Alert
2.24
Katwarn
2.27
Hyeres Risque
2.29
IGAD-ASIGN
2.32
MyPredict
2.37
Lastquake
2.43
Risque Nice
2.49
Semarang Disaster Alert
2.50
FEMA
2.65
My Public Alert & Notico
2.69
HelpMe
2.83
Qwidam
2.88
Signalert Pro
3.03
Vialert
3.09
ELERT
3.49
Legend
1 : Alert ; 2 : Interactivity ; 3 : multi-hazards; 4 : attractivity
Score < 0.25
Score de 0.26 à 0.50
Score de 0.51 à 0.75
Score > 0.76
Score = 1
E. Bopp et J. Douvinet, UMR ESPACE 7300 CNRS

Figure 3. Classification comparing the 50 applications according to all calculated indicators.

LIMITATIONS

In this paper, we evaluated the effectiveness of smartphone applications in case of disasters. As research on this matter is still at an early stage, more studies need to be done to develop the calculation of weighted settings and to quantify the performance of people in using such solutions.

Several limits could be stated in our study. The choice of the weighting coefficients has a significant influence on the results. Thus, if we remove the weighting of settings, giving each one an equivalent weight, we obtain a variation of values ranging from -1.09 to 0.97 (figure 4), which is high for global indices between 0 and 4. However, the weighting is based precisely on results from the scientific literature, and not giving weight to certain criteria would therefore make no sense.

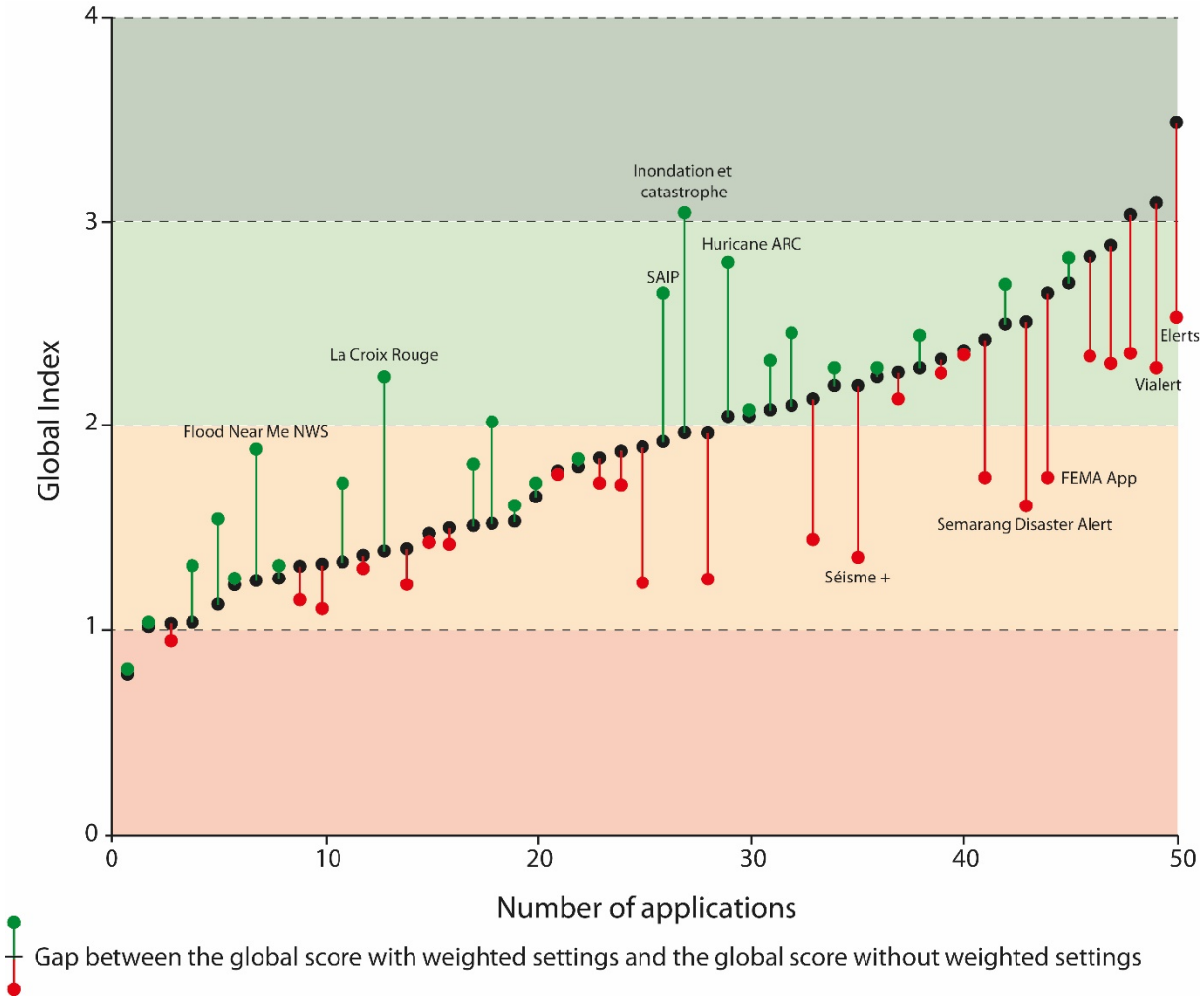


Figure 4. Gap of results between weighted and unweighted settings

Many applications do not obtain good indicators, regardless of the calculation method. This work suggests that many of them do not really answer to the main objectives retained for alerting humans in case of disasters.

Another limit is the quantification of the response phase behavior of people (Lindsay, 2011). It seems to be not useful to create a ready-for-use smartphone application without ensuring training and support. Downstream information has already shown its inefficiency, both in the fields of prevention and alert in France (Vinet, 2010). As such, we must avoid keeping the same thinking scheme. Moreover, without real appropriation of these new means by the citizens, applications could disappear as fast as they emerged (Douvinet, 2018).

Due to a lack of data, this work did not assess how application managers proceed to send an alert or process information from users. Some managers make the choice to automatically switch information from official organizations in the forecast of hazards (Météo-France, Vigicrues, BRRM, etc.). Other managers set up an on-call duty team to process all the information in real time. But this information is not available for all evaluated applications. The download number was also not taken into account because of confusing data: download ranges on Google Play® are too wide and there is no information on removing applications by users.

DISCUSSIONS

Clearly, this work has well shown that the studied solutions do not reach their objectives and it undoubtedly adds further misunderstanding for citizens. This is paradoxical because, the pervasive aspect of smartphone makes it possible to hold cross-cutting discussions between various stakeholders (citizens, institutions and associations) and facilitates quicker information. The faster signals may be detected (for example, pictures showing damages), the faster managers may be able to trigger emergency response actions and the sooner they may be able to support citizens and provide relief to victims. But a problem remains to be solved: citizens can spread false or wrong information through applications and the Internet. False information are spread "significantly farther, faster, deeper, and more broadly than the truth in all categories of information" through Social Medias (Vosoughi *et al*., 2018). However, mass participation in crowdsourcing tends to rectify the place of false information in Social Medias (Alexander, 2014). Several groups are attempting to increase the veracity and the accuracy of crowdsourced data (like "Hacker Against Natural Disaster") and "the cost of responding to a false alarm is far less than not responding" (Riccardi, 2016).

In France, authorities are unable to use this technology because of institutional regulatory protocols that are not designed to manage such fast-paced timescales (Vogel, 2017). The establishment of "community managers" by the crisis center is a first step but remains insufficient. This issue must be solved to dramatically improve warning systems. In the field of smartphone applications, the collaborative aspect could be improved in three stages: 1) before a disaster occurs, awareness campaigns, collection of data, and training for citizens-sensors should be carried out, which could lead to selection or specialization of "citizen monitors" (a specific role entrusted to each users according to their abilities) ; 2) during the crisis, collecting information in real-time would be greatly facilitated by upstream training, aiming to only pass reliable information on. Therefore, monitors could also turn into "stakeholder", able to move by following guidelines taught in the upstream phase and to act within the area where the crisis is occurring. Guidance provided by a rescue center in real-time is also a possibility; 3) downstream of the crisis, there is a need of taking into account the evolution of the crisis, witnessing and enabling institutional aid to improve training, intervention and crisis management processes. These steps aimed at strengthening the prevention of human and material damages during current or exceptional disasters. This method requires much more support than mere data collection applications such as crowdsourcing or crisis-mapping (Douvinet *et al*., 2017). It is crucial to recommend the use of real-time operational systems, awareness and training measures.

Otherwise, to enhance applications uses, there is an urgent need to sensitize the citizens to commit the "internet of things" and organize training exercises (Gisclard, 2017). In that respect, smartphone applications boost discussions around resilience, which defends the idea that a population must be autonomous (it may be isolated in times of danger), united and involved before being able of using the existing tools. However, in places where the perception of risk is low, the Cell Broadcast might be more appropriate than an application to alert citizens. Cell Broadcast is a message sent to cell phones in a predefined area and does not require the download of an application (which requires a minimum of risk culture). This means does not allow interactivity between users and crisis managers but it allows to alert effectively and quickly a large number of citizens. Smartphones are also expensive objects, less used by old and less graduated people and dependent on the Internet network. Thus, these tools increase territorial and social disparities and their use must be done in addition to other means of alert.

CONCLUSIONS

This study evaluated a method to classify and compare different smartphone applications dedicated to alert in France. The application evaluation was focused on four points: 1) their ability to alert users; 2) their ability to be interactive; 3) their ability to take into account the 12 majors risks identified in France; 4) their attractiveness.

Surprisingly, few of them really reached the original objectives, while many claimed to be as such. Many applications have limited potential because it doesn't take into account the possibility of interactivity enabled by smartphones. We must give citizens the ability to interact with alerting means. This criterion is a prerequisite for the implementation and appropriation of smartphone applications by citizens (Coleman *et al*., 2009; Gisclard, 2017). Moreover, many studied solutions have a vision of the hazards which is limited to the scale of their territory. These results reflect two restrictive choices made my managers. Firstly, they not consider citizens as an actor able to observe and communicate during crises. Secondly, they forget the fact that a territory is often subject to various risks, and that more complex or unpredictable phenomena (cascading effects, simultaneous risks) can occur there.

Our results need larger-scale debate. It raises this specific question: it is necessary to multiply the solutions at local scales, for increasing the understanding of dangers by residents, or does the French government have urgently to display a new national smartphone application, even after the issues observed in the use of SAIP® during two years? Our results in this work highlight large-scale solutions because local solutions present more problems in their software and functionality, and induce inequalities between territories and humans. Whatever the discussions arise from the type of indicators, the nature of retrieval method or the weighted coefficients allocated to several parameters, this work argues that the high number of applications strongly induces confusion and concurrence between stakeholders implicated in the alert process. In the same time, the emergence of numerous smartphone applications reveals a lack in the actual political choice carried out by the institutions. Finally, the institution must take into consideration connected objects to develop systems different from the sirens which remain the main tool used in France.

REFERENCES

Adoue F. (2015), « Information en temps réel et optimisation du déplacement: L'usage des applications pour smartphone dans et autour des transports en commun franciliens ». *Netcom*, nº 29-1/2 (décembre), pp. 37-54. https://doi.org/10.4000/netcom.1852.

Aloudat A., Michael K., Al-Debei M. (2014), Social acceptance of location-based mobile government services for emergency management. *Telematics and informatics* n°31, pp. 153-171.

Barcenilla J., Bastien J. M. C. (2009), L'acceptabilité des nouvelles technologies : quelles relations avec l'ergonomie, l'utilisabilité et l'expérience utilisateur ? *Le travail humain* vol.72, pp. 311-331.

Barr N., Pennycook G., Stolz J. A., Fugelsang J. A. (2015), The brain in your pocket: Evidence that smartphones are used to supplant thinking. *Computers in Human Behavior*, vol. 48, pp. 473-480.

Becker D., Bendett S. (2015), Crowdsourcing solutions for disaster response: examples and lessons for the US Government. *Procedia Engineering*, vol. 107, pp. 23-33.

Ben Mena S. (2001), Une solution informatisée à l'analyse de sensibilité d'Electre III. *Biotechnologie, Agronomie, Société et Environnement 4*, pp. 31-35.

Bopp E., Douvinet J., Serre D. (2019), « Faire un tri dans le monde des applis ». Expérimentation sur 50 applications smartphones proposant d'alerter la population face aux risques majeurs en France. *Netcom*, [en ligne] : https://journals.openedition.org/netcom/3531.

Brownlee B., Liang Y. (2011), Mobile ad hoc networks: an evaluation of smartphone technologies. Royal Military College of Canada, 40p.

Bruns A., Liang Y.E. (2012), Tools and methods for capturing Twitter data during natural disasters. *First Monday, peer-reviewed journal on the Internet*. Vol. 17, number 4.

Budhathoki N., Nedovic-Budic Z., Bertram C. B. (2010), « An interdisciplinary frame for understanding volunteered geographic information ». *Geomatica* 64 (1), pp. 313-20.

Carley, K. M., Malik, M., Landwehr M. Pfeffer, J., Kowalchuk, M., (2015). Crowd sourcing disaster management: the complex nature of Twitter usage in Padang, Indonesia, *Safety Science*, 90, 48-61.

Chatzimilioudis G., Konstantinidis A., Laoudias C., Zeinalipour-Yazti D. (2012), « Crowdsourcing with Smartphones ». *IEEE Internet Computing* 16 (5), pp. 36-44. https://doi.org/10.1109/MIC.2012.70.

Choy S., Handmer J., Whittaker J., Shinohara Y., Hatori T., Kohtake N. (2016), Application of satellite navigation system for emergency warning and alerting. *Computers, Environment and Urban Systems*, vol.58, pp. 12-18.

Coyle D., Meier P. (2009), *New Technologies In Emergencies and Conflicts: The Role of Information and Social-Networks.* Washington, D.C. and London, U.K.: UN Foundation-Vodafone Foundation Partnership.

Daupras F., Antoine J. M., Becerra S., Peltier A. (2015), Analysis of the robustness of the French flood warning system: a study based on the 2009 flood of the Garonne River. *Natural Hazards*, vol.75, n°1, pp. 215-241.

De Longueville B, Smith R. S., Luraschi G. (2009), « "OMG, from Here, I Can See the Flames!": A Use Case of Mining Location Based Social Networks to Acquire Spatio-Temporal Data on Forest Fires ». In, 73. ACM Press. 8p. https://doi.org/10.1145/1629890.1629907.

DGSCGC. (2013), *Guide Orsec. Alerte et information des populations*. Ministère de l'Intérieur. Vol. 6.4, 91p.

Donahue A. K., Tuohy R. V. (2006), Lessons We Don't Learn A Study of the Lessons of Disasters, Why We Repeat Them, and How We Can Learn Them. Homeland Security Affairs, vol.2 n°2, 29p.

Douvinet J., Gisclard B., Kouadio J. (2015). SMARS Seminar **:** Les Smartphones et les Réseaux Sociaux comme outils d'aide pour l'alerte face aux crues rapides. Avignon.

Douvinet J, Gisclard B., Kouadio J. S., Saint-Martin C., Martin G. (2017), « Une place pour les technologies smartphones et les Réseaux Sociaux Numériques (RSN) dans les dispositifs institutionnels de l'alerte aux inondations en France ? » *Cybergeo*, janvier. https://doi.org/10.4000/cybergeo.27875.

Douvinet J. Janet B. (2018), « La place de l'alerte institutionnelle dans la chaîne de prévision en France » dans Vinet F. (dir.) *Inondations 2. La gestion du risque.* Iste Edition, Londres, pp. 211-226.

Douvinet J. (2018). Smartphone applications, a means to promote for emergency management in France? In Sedes F. (Eds*), Information system for Alarm Diffusion, ISTE Publications*, in press.

Fajardo J. T. B., Oppus C. M. (2009), « A mobile didaster management system using the Android technology ». *International journal of communications* 3 (3), pp. 77-86.

Fragkiadakis A. G., Askoxylakis I. G., Tragos E. Z., Verikoukis C. V. (2011), Ubiquitous robust communication for emergency response using multi-operator heterogeneous networks. *EURASIP Journal on Wireless Communications and Networking*, n°1, 16p.

Gaillard J.-C, Wisner B., Benouar D., Cannon T., Créton-Cazanave L., Dekens J., Fordham M., et al. (2010), *Alternatives pour une réduction durable des risques de catastrophe*. Vol. 3, pp.66-88.

García C. (2012), « Concevoir et mettre en place un Système d'Alerte Précoce Intégré plus efficace dans les zones de montagnes : une étude de cas en Italie du Nord ». *Revue de géographie alpine*, nº 100-1 (avril), 13p. https://doi.org/10.4000/rga.1672.

Gisclard B. (2017), « L'innovation sociale territorialisée : un levier de réappropriation du risque inondation par les habitants. L'exemple des crues rapides dans les territoires ruraux du Gard et du Vaucluse (France) ». Thèse soutenue à l'Université d'Avignon et des Pays du Vaucluse, France, 412p.

Goodchild M. F. (2007), « Citizens as Sensors: The World of Volunteered Geography », 15p.

Hertig E., Tramblay Y. (2016), Regional downscaling of Mediterranean droughts undr past and future climatic conditions. *Global and Planetary Change*, vol. 151, pp. 36-48.

Horita F., Degrossi L., Assis L.F., Zipf A., De Albuquerque J. (2013), « The use of Volunteered Geographic Information and Crowdsourcing in Disaster Management: a Systematic Literature Review ». In *19th Americas Conference on Information Systems, AMCIS 2013 - Hyperconnected World: Anything, Anywhere, Anytime*. Vol. 5.

Kelman I. (2011), Understanding Vulnerability to Understand Disasters. *Canadian Risk and Hazards Networks*: Toronto, ON, Canada, 14p.

Kouadio J. (2016), « Les technologies smartphone comme outils d'aide à l'alerte face aux crues rapides en France : Expérimentation dans le Vaucluse et le Var ». Thèse soutenue à l'Université d'Avignon et des Pays du Vaucluse, France, 267p.

Lagadec P. (2011), Le citoyen dans les crises. Nouvelles donnes, nouvelles pistes. *Préventique Sécurité*. Num. 115, pp.25-31.

Laurila J. K., Gatica-Perez D., Imad A., Blom J., Bornet O., Do T. M. T., Dousse O., et al. (2013), From big smartphone data to worldwide research: the mobile data challenge. *Pervasive and Mobile computing* vol 9, n°6, pp752-771.

Linardi S. (2016), Peer coordination and communication following disaster warnings: an experimental framework. *Safety Science*, vol.90, pp.24-32.

Lindsay B. R. (2011), « Social Media and Disasters: current uses, future options, and policy considerations ». 7-5700. Congressional Research Service.

Liu B. F., Wood M. M., Egnoto M., Bean H., Sutton J., Mileti D., Madden S. (2017), « Is a Picture Worth a Thousand Words? The Effects of Maps and Warning Messages on How Publics Respond to Disaster Information ». *Public Relations Review* 43 (3), pp. 493-506. https://doi.org/10.1016/j.pubrev.2017.04.004.

Matveeva A. (2006), Early Warning and Early Response: Conceptual and Empirical Dilemmas. European Centre for the Conflict Prevention, issue 1, 66p.

Maystre L. Y., Pictet J., Simos J. (1994), *Méthodes multicritères ELECTRE. Description, conseile pratiques et cas d'application à la gestion environnementale.* Presse Polytechniques et Universitaire Romandes. Lausanne. 327p.

Nadim F., Liu Z. (2013), « Nex methodologies for multi-hazard and multi-risk assessment methods for Europe ». MATRIX project 265138. 11p.

Okolloh Ory. (2009), « Ushaidi, or "testimony": Web 2.0 tolls for crowdsourcing crisis information ». *Participatory learning and action*, nº 59, pp. 65-70.

Poushter J. (2016), Smartphone ownership and Internet usage continues to climb in emerging economies. 45p.

Riccardi M. T. (2016), The power of crowdsourcing in disaster response operations. *International Journal of Disaster Risk Reduction*, vol.20, pp. 123-128.

Serre D. (2005), Evaluation de la performance des digues de protection contre les inondations. Modélisation de critères de décision dans un SIG. PhD in Environment. Université de Marne la Vallée. Français. 367p.

Saaty T. L. (1984), Décider face à la complexité : une approche analytique multicritère d'aide à la décision. ESF Editeur, 236p.

Shan H-Y., Lai Y-L. (2015), « Smartphone application and management system for disaster resistant community ». In Australian and New Zealand Disaster and Emergency Management Conference, 11p.

Slingby A., Beecham R., Wood J. (2013), Visual analysis of social networks in space and time using smartphone logs. *Pervasive and Mobile Computing* 9, pp. 848-864.

Sorensen J. H. (2000), Hazards Warning Systems: Review of 20 Years of Progress. *Natural Hazards Review*, vol.1, n°2, pp119-125.

Tang K., Wang Y., Liu H., Sheng Y., Wang X., Wei Z. (2013), Design and Implementation of Push Notification System Based On the MQTT Protocol. International Conference on Information Science and Computer Application.

Väätäjä H., Koponen T., Roto V. (2009), Developing practical tools for user experience evaluation: a case from mobile news journalism, European Conference on Cognitive Ergonomics, Helsinki, Finland, p. 23:1-23:8.

Villela K., Nass C., Novais R., Simoes P., Traina A., Rodrigues J., Menéndez J.M., Kurano J. *et al.* (2018), Reliable and Smart Decision Support System for Emergency Management Based on Crowdsourcing Information. Exploring Intelligent Decision Support Systems. Springer, Cham, 2018. Pp. 177-198.

Vinet, F. (2010). Le risque inondation, diagnostic et gestion. Paris, France : Lavoisier.

Vinet F., Boissier L., Saint-Martin C. (2017). Flashflood-related mortality in southern France: first results from a new database, FloodRisk, European Conference, 6 p.

Vogel J-P. (2017), « Deuxième partie une mise en œuvre perfectible des deux principaux volets du SAIP, marqués par d'importants retards ». Rapport d'information n°595, au nom de la commission des finances sur le système d'alerte et d'information des populations (SAIP), 48p.

Vosoughi S., Roy D., Aral S. (2018), The spread of true and false news online. *Science*, vol.359, n°6380, pp. 1146-1151.

Weinlich P., Semeradova T., Kubat D. (2014), « Design of an early warning mobile application ». Networking Societies. Cooperation and conflicts, 22nd Interdisciplinary Infrmation Management Talks, Podebrady, Czech Republic, pp. 37-44.

Ziemke J. (2012), Crisis Mapping: The Construction of a New Interdisciplinary Field? Journal of Map & Geography, vol.8, n°2, pp. 101-117.

Identifying potential landslide location using Unmanned Aerial Vehicles (UAVs)

Jorge Vargas-Florez
Pontifical Catholic University of Peru, PUCP
jorge.vargas@pucp.edu.pe

Grovher Palomino
National University of Engineering, UNI
wpalomino@inictel-uni.edu.pe

Andres Flores
Pontifical Catholic University of Peru, PUCP
dflores@pucp.edu.pe

Gloria Valdivia
National University of Engineering, UNI
g_valdiviacamacho@yahoo.com

Carlos Saito
Pontifical Catholic University of Peru, PUCP
csaito@pucp.pe

Daniel Arteaga
National University of Engineering, UNI
darteaga@inictel-uni.edu.pe

Mario Balcazar
Pontifical Catholic University of Peru, PUCP
mbalcazar@pucp.edu.pe

Miguel Fernandez
Pontifical Catholic University of Peru, PUCP
mfernandezp@pucp.edu.pe

José Oliden
National University of Engineering, UNI
jose.oliden@gmail.com

Daniel Díaz
National University of Engineering, UNI
ddiaz1610@gmail.com

ABSTRACT

The impact of landslides is determined by the previous state of vulnerability and susceptibility present in a community. Vulnerability is related to physical aspects and susceptibility is defined as the propensity or tendency of an area to be affected by the occurrence of a given hazard. Knowledge of geography allows us to characterize and measure some of these factors. For example, in landslides called huaicos in Peru, these are related to the existence of a slope and soil type of the hills favorable to the loosening of land masses, as well as the increase in rainfall and the presence of streams. The use of UAVs (Unmanned Aerial Vehicles, commonly called drones) for the identification of susceptibility zones is presented in this paper. The result is positive for using the georeferenced data to identify potential landslide flow using as unique criterion surface slopes.

Keywords

Susceptibility mapping, disaster prevention, landslides, drones.

INTRODUCTION

Within the mitigation stage, decisions are made taking a strategic perspective to reduce the potential impacts of a disaster or to avoid it; thus, risk analysis is normally part of this stage (Altay and Green III, 2006; Leiras et al., 2014). Vulnerability and susceptibility maps become enormously important, because it allows knowing in advance, where the most exposed and dangerous areas are located. These tools support elaborate qualitative and quantitative information, such as: forecast impacts post disasters, evaluate options of preventive intervention, risk control planning (using elimination, isolation or reduction strategies), guide where the investment of infrastructure to mitigate vulnerability must be made, determine the sociodemographic characteristics of the

threatened territory (MINEDU, 2015). Nowadays, vulnerability maps are widely used by various public organizations, non-governmental organizations and companies to track, evaluate and manage the different risks to which they are exposed.

Risk mapping is the presentation of the results of risk assessment on a map, showing the levels of expected losses which can be anticipated in specific areas, during a period, because of disaster hazards. The risk is defined as the combination of the probability of an event and its negative consequences (UNISDR, 2009). The latter is related to expected losses such as fatalities, persons injured, damage to property, and disruption to economic activity, etc. caused by a hazard (Coburn et al., 1994). Risk assessments include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process (UNISDR, 2009). Zhao and Chen (2015) present a methodology for the risk assessment (see Figure 1). The process of risk assessment is based in a mesh spatial representation, where an entire region is divided into a few fine spatial meshes with a specific risk value. The procedure considers both hazard sources and risk targets (hospitals, schools and commercial centers, etc.). For each mesh, the risk level is calculated considering the severity and vulnerability level. The severity measures the intensity and frequency of the hazard. The vulnerability measures social indicators, such as population and its structure, the accessibility of emergency resources, etc. Mapping and disaster assessment can improve the provision of timely and accurate support for activities such as evacuation, sheltering and distribution (Rodríguez-Espíndola et al., 2016).

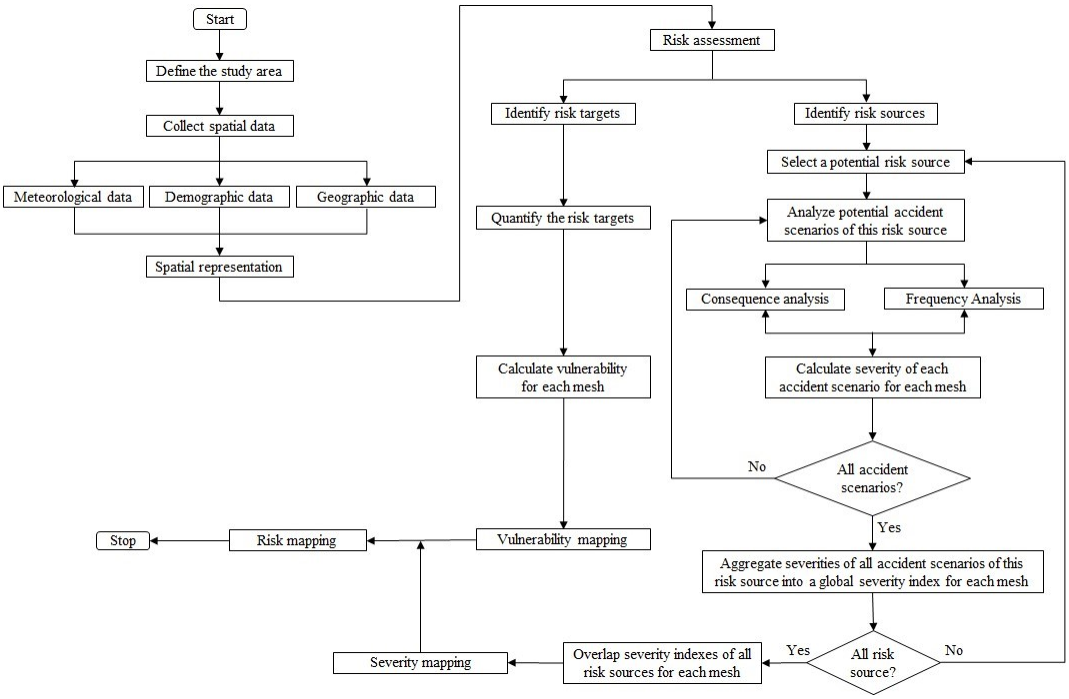


Figure 1. Flowchart of risk assessment and mapping (Zhao & Chen, 2015)

According to Lewis (2004) "vulnerability" is related to physical aspects and "susceptibility" to a previous weakness of capacity to manage it. In many cases, it is necessary to settle for a qualitative classification in terms of high, medium and low; or explicit statements concerning the disruption likely to be suffered (Coburn et al., 1994). Susceptibility is defined as the propensity or tendency of an area to be affected by the occurrence of a given hazard (Ayala-Carcedo, 2002). The categories used for a susceptibility analysis can be (Rauld et al., 2015): (1) Very High; there are very favorable conditions and there are several recorded events, (2) High; there are favorable conditions and there are sporadic events recorded, (3) Moderate; there are some favorable conditions and / or practically no catastrophes of danger and (4) Low / Null; no favorable condition to some event. Hence, susceptibility and vulnerability mapping are considered one of the most important steps in disaster risk reduction because it identifies elements (areas and communities) propensity to be affected by a disaster, they are important for disaster risk management planning (Isma'il and Saanyol, 2013).

Hazard risk vulnerability mapping is considered one of the most important steps in disaster risk reduction because it keeps identifying vulnerable areas to be considered into plans for disaster risk management (Isma'il and Saanyol, 2013). Next level to risk maps are the susceptibility and hazard maps as expression of the probability of occurrence of a certain event in a location and period of time, the higher level corresponds to maps that take into account not only the phenomena themselves and their probability but how they affect people and goods (exposure) and its economic, psychological and social valuation, or in terms of the degree in which they are affected (vulnerability); finally, the product of the hazard, elements at risk valuation and vulnerability results in risk assessment (Fernández et al., 2013).

Different tools are available to make susceptibility and vulnerability maps; we have the traditional ones related to cartography, topographic and geographic, which make maps of the location of the threats (plate tectonics, mountain streams, soil types, etc.). Others include new technological tools available today with mobile communication devices such as those with a geographic system integrated with GPS, remote sensing and fuzzy logic to generate a real-time evaluation or simulation to determine the presence of contaminating sources of impact (Corwin et al., 1996). Vulnerability mapping is also done in the frame to understand social vulnerability and to more easily identify areas of vulnerable population (IWR, 2013).

However, technology still has limitations and obstacles, such as the case of digital cartography, whose main challenge is to achieve preventive analysis of threats, based on reliable approximation of data from different hazards on the same space (Perles and Cantero, 2010). As well as an important amount of high-quality data to be able to analyse and elaborate valid and reliable vulnerability maps (Esteller et al., 2002). To overcome some problems mentioned, the use of drones is proposed as an alternative to play an important role, in obtaining data and information related to the mapping of vulnerabilities in a territory exposed to threats. This advanced equipment of hardware and easy manoeuvrability allows the capture of large amounts of information thanks to the various integrated sensors (Ramírez et al., 2013).

To acquire situational awareness of the disaster an accurate map and 3D model of the affected terrain can be obtained using aerial images and photogrammetry techniques. Such images have been obtained using drone technology in two phases using different kind of aircraft: fixed wing and multirotor. Each one is used for specific missions depending on the type of mapping required.

The paper is organized as follows, first the theoretical framework based on the understanding of geographic information systems (GIS) will be presented, then the systems of drones for the use of disaster monitoring, shortly after the contribution of this work, which is the development of maps of vulnerability and prognosis of some affected areas for the study area. Finally, the discussion and conclusions parts, adding proposals of future works of investigation, are presented.

GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Rodríguez-Espíndola et al. (2016) show the capabilities of Geographical Information System (GIS) for disaster management and the analysis potential flooding scenarios to provide information for an optimization model of location and distribution. The work is applied to two real-world floods in Mexico. The results provide evidence that including GIS analysis for a decision-making tool in disaster management can improve the outcome of disaster operations by reducing the number of facilities used at risk of flooding. Cutter (2003) highlights the applications of GIS to the emergency response cycle, citing examples from natural hazards and suggests some important research areas based on the needs of the disasters and emergency management. Other studies on information systems applications, vulnerability and risk mapping in humanitarian logistics can be found in the literature: Chen et al. (2018); Hu et al. (2016); Isma'il and Saanyol (2013); Kumar and Anbalagan (2015); Muthukumar (2013); Özdamar and Ertem (2015); Tomaszewski et al. (2015). GIS applications in Disaster Management are progressively turning into a necessary component of disaster and emergency management activities in many parts of the world. The spatial dimension of geospatial data makes it exceptionally critical for decision-makers in the different phases of emergency management operations. It is important for policy makers to have the right information to permit them to react, mitigate and manage catastrophes (Abdalla, 2016).

DRONE SYSTEM IN DISASTER RISK MANAGEMENT

Unmanned Aerial Systems (UAS) have considerable potential to radically improve monitoring. UAS-mounted sensors offer an extraordinary opportunity to bridge the existing gap between field observations and traditional air and space-borne remote sensing, by providing high spatial detail over relatively large areas in a cost-effective way and an entirely new capacity for enhanced temporal retrieval (Lin et al., 2016, Manfreda et al., 2018, Tanzi et al., 2014).

Elaboration of vulnerability maps by drones have numerous benefits to support decision-making for reducing

the vulnerability of communities, through utilisation of information to mitigate or reduce the impact of social disasters (Ismail-Zadeh and Cutter, 2015), and taking care of vital infrastructure such as electricity, water, transport, health and safety (Sandholz, 2018). Other ones applied in poor communities and their surroundings are the monitoring and execution of action plans, the simulation of models for the prevention of disasters, improvement in the precision and quality of urban-environmental planning and the relatively fast speed of data is collected (UNEP-DHI Partnership, 2017).

Based on experience from the authors, who deal with drone projects in different applications related to agriculture, cartography etc. (GISANT, which is the Unmanned Aircraft Systems Research group at Pontifical Catholic University of Peru, PUCP, http://investigacion.pucp.edu.pe/grupos/gsant/ and the National Telecommunications Research and Training Institute, INICTEL, a research group from National University of Engineering, UNI, http://didt.inictel-uni.edu.pe/didt/index.php/grupo-de-procesamiento-de-senales-e-imagenes-g-psi/) with the support the Crisis and Disaster Management group at PUCP, an interinstitutional and multidisciplinary (industrial, electronic and mechatronic engineers) research group to deal with this project was created. Three main phases are proposed to run a drone-mapping project. The first phase of the drone-susceptibility mapping project involves the acquisition of data from a wide area perspective, to swiftly acquire information on a large scale. For this task, a fixed wing aircraft is used. Images are acquired and are processed using of the shelf software to obtain 3D models and mapping. These maps will be crucial to detect affected areas by potential landslides; these specific sites need to be properly mapped in more detail, for which the second phase is put into operation. The second phase involves the use of multirotor aircraft which can fly lower and acquire detailed data to assess the situation and provide the necessary information for relief decision making. A final third phase relates the processed image information with previous threat conditions as cliffs, unsteady slopes, type of soil, presence of ravines, etc. which create susceptibility conditions and let identify potential affected by future landslides to be triggered by the increase of raining periods like El Niño phenomenon.

SYSTEM OVERVIEW

According to the report of the National Emergency Operations Center, COEN (2017) in Peru, since January 14, 2017, heavy rainfall was recorded because of the presence of Coastal El Niño, affecting the districts of Lurigancho-Chosica and Chaclacayo in Lima (Peru's capital), causing huaicos, affecting homes, communication routes, educational institutions and damage to the life and health of people. On March 16, 2017, at 4:30 p.m., the overflow of the waters of the Jicamarca ravine (Huaycoloro River) was recorded, and at 9:00 p.m., the overflow of the Rímac River was reported, causing the affectation of road bridges, housing, public places, communication routes and flooding in several sectors of the districts of San Juan de Lurigancho, El Agustino, Lurigancho-Chosica. On March 19 at 12:30 a.m., because of the intense rainfall, the Chillón River overflowed also, affecting cultivation areas in Carabayllo sector.

According to information found at the search engine service for information on disasters and their impact in Peru (see Figure 2), named the National Information System for Response and Rehabilitation, SINPAD (http://sinpad.indeci.gob.pe/sinpad/Estadistica/Frame_Esta_C7.asp) from the National Institute of Civil Defense of Peru, INDECI ; it was selected the town of Huatocay and its surroundings, in the district of Carabayllo as the study area because of 3450 casualties reported (see Figure 3). With the support of a seed fund of research by Penn University, researchers from UNI and PUCP, teamed up to design a humanitarian supply chain to 2017 Coastal El Niño affected communities from Huatocay. It was determined by the research group that the starting point would be to identify susceptibility areas to landslides. To carry out the field work, contact was made with the authorities and local inhabitants to receive support for the search of the appropriate places to be used for the drone flight work. Other benefits of the inclusion of authorities and residents in the realization of these works, are the transfer of knowledge and experience for disaster management, through the management of drone flight equipment, evaluation of areas of risk, control of existing threats, etc. The limitations for the development of this population inclusion strategy, to carry out the fieldwork has to do with the level of education and budget of the local authorities to carry out disaster prevention activities.

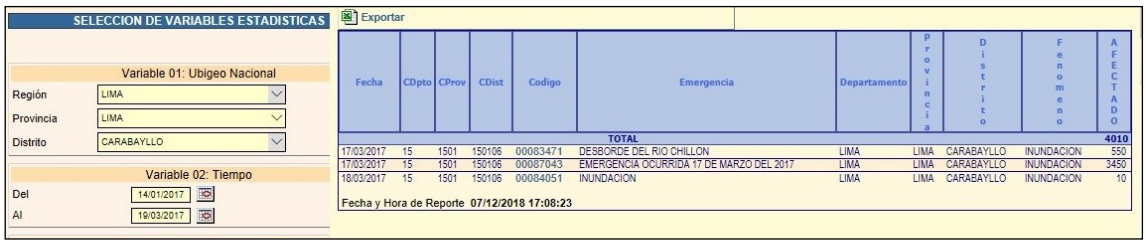


Figure 2. The National Information System for Response and Rehabilitation, SINPAD

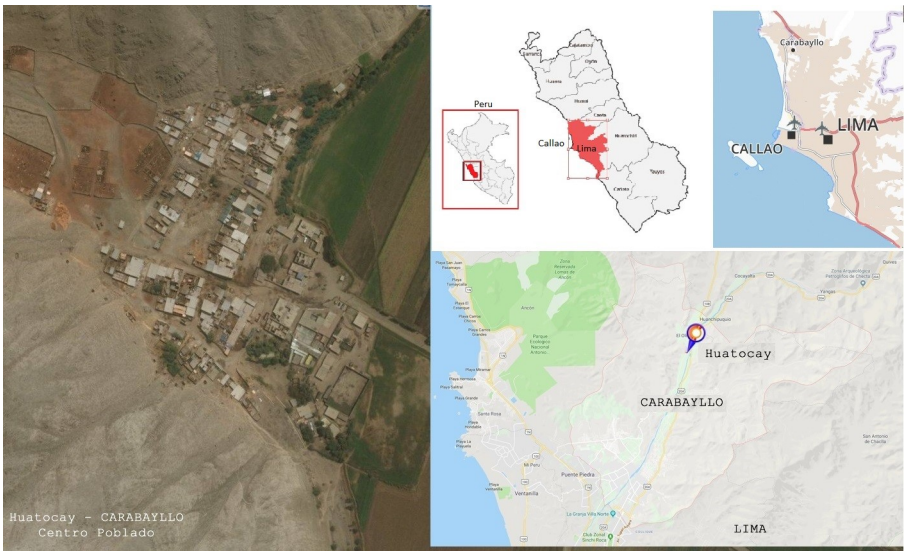


Figure 3. Huatocay location in Carabayllo, Lima region, Peru

Phase One: Fixed Wing Aircraft

The system features an 1880 - Skywalker aircraft frame. It is described as a flying wing UAV model made of highly dense foam and it has four main components: one fuselage, one elevon and two wings. Figure 4 shows the frame of the current prototype. This type of UAV has control surfaces on the wing as ailerons, horizontal and a vertical stabilizer on the tail as elevator and rudder to control roll, pitch and yaw during flight. The fuselage or main body was modified to house the Avionics, Propulsion and the Image Acquisition Systems components. Figure 5 shows an overview of the entire system.

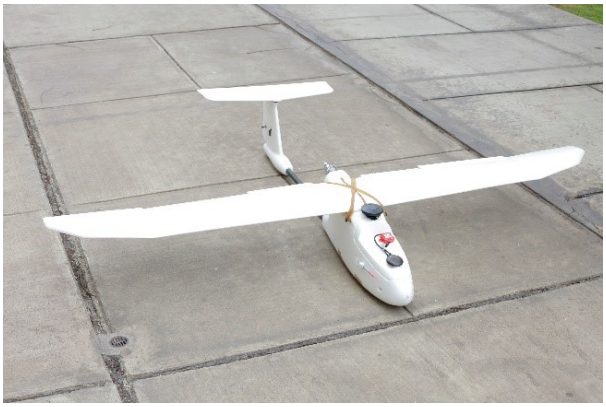


Figure 4. 1880 - Skywalker UAV model for multipurpose appliances

Avionics System

The Avionics System is built around the Pixhawk2 autopilot from Hex Technology Limited, whose tasks include the control of all the actuators of the UAV, reception of sensor information for state feedback for the system control algorithm, trajectory planning, and signal reception from the Ground RC Controller, among others. The Pixhawk2 controls each surface of the aircraft to follow the flight plan that is uploaded before each flight. The control algorithm used is based on PIDs that synchronize the movements of the electric servos on each control surface on the wings to follow the designated waypoints on the flight plan. Each waypoint has a known altitude, latitude and longitude coordinate that it is used to guide the UAV. For this purpose, the Pixhawk2 uses several important components, which will be described in the following paragraphs:

- A GPS Receiver, to get the UAV's geographical location and heading in the world.
- An Airspeed sensor, to get the current wind airspeed (and consequently the UAV speed) and calculate the altitude from pressure data.
- A telemetry radio, to inform a Ground Station about the status of the UAV and the mission.

- A RC Receiver, to get the RC signals from a ground controller for manual control of the UAV and to receive the command to start autonomous flight.
- An embedded IMU, for information regarding UAV attitude.
- An embedded barometer, to calculate the pressure altitude over sea level.

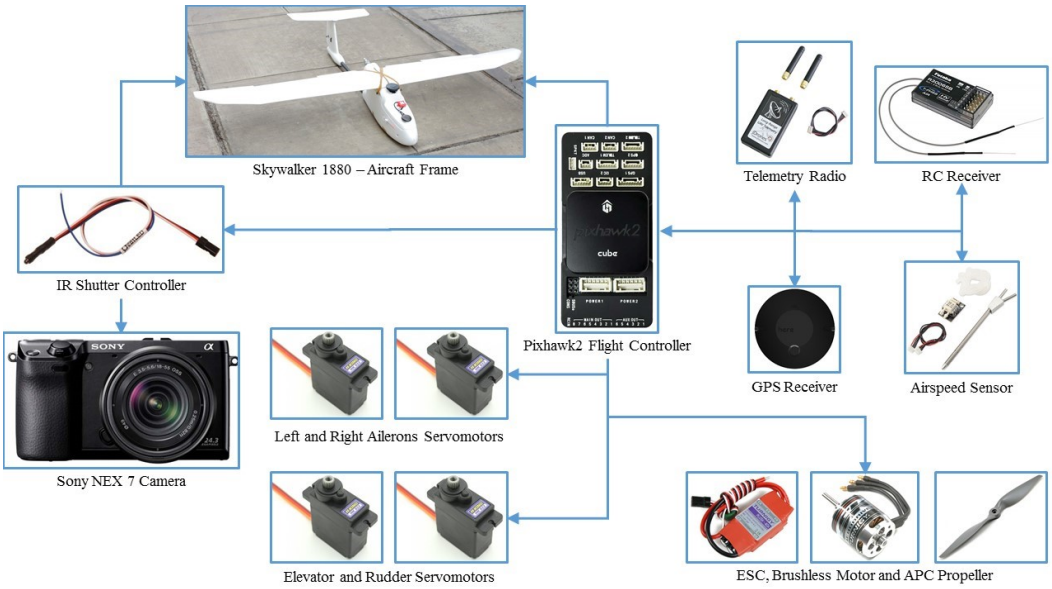


Figure 5. An overview of the fixed-wing UAV proposed system

Propulsion System

The Propulsion System is responsible for generating the thrust required by the UAV to move forward and control the speed of the aircraft, which is important to generate enough lift during take-off operations. Its main components are one Turnigy Motor ® 700KV brushless motor, one 4S – 8000mAh Li-Po battery and a 10″×7″ foldable plastic propeller.

Image Acquisition System

For the task of acquiring and storing images, a Sony NEX 7 camera is used to capture of 24.3 megapixels images. The Pixhawk2 navigation controller sends the necessary signal to trigger the camera.

Methodology for Data Acquisition and Processing

This part is composed of the following sub steps planning and operations: terrain inspection for take-off and landing operations, flight planning for trajectory, 3D reconstruction and surface flow model.

Terrain Inspection for Take-Off and Landing Operations

After arriving at the area of operations, the surrounding environment must be inspected to determine suitable terrain for the Take-Off and Landing Operations. A smoother land of considerable extension must be found to carry out a successful landing. Moreover, take-off operations, although not as dangerous as landing ones, require a place where the ground offers stable footing since, propulsion must be provided by a human operator, who must gain speed by running and throw the aircraft while the pilot activates the throttle.

Flight Planning (Trajectory Determination)

Test flights were carried out near Chillón River in Perú over two regions (76°58'58.713"W, 11°43'55.006" S) and (76°56'21.394"W, 11°42'28.940" S) on March 28, 2018. Each flight plan was made using the Mission Planner software considering a 75 percent overlap between images and flight lines. The terrain and weather are important factors to consider during the preparation of each flight plan. To overcome these difficulties, the flight plans are designed so that the UAV will fly alongside the direction of the wind and against it when the wind

speed is relatively low to save energy. To determine where the photos are to be taken along the trajectory, a distance-based system is employed, meaning that the cameras will be triggered each time the aircraft travels a determined distance inside the area of interest. This allows the images to maintain the desired degree of overlap since they are taken at regular position intervals, unaffected by wind speed or aircraft velocity. Moreover, flight trajectory is also determined by the image resolution of the camera. In Figure 6, the flight trajectory for the flying missions of two areas near Chillón River is shown. For these flights, a relative altitude of 150 meters was chosen, so to cover the entire area, the trajectory could afford to be sparse and with few lines for the aircraft to go through.

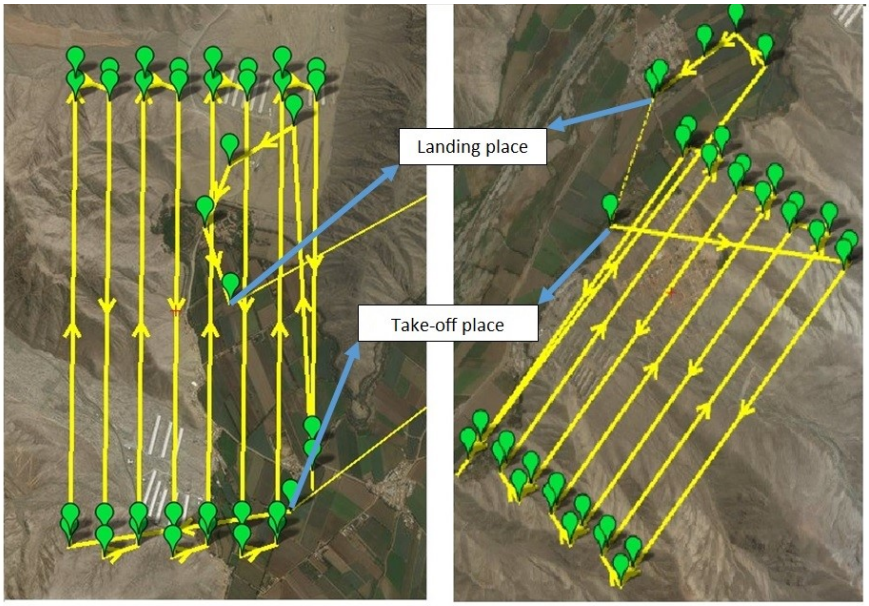


Figure 6. Flight trajectory of the two flying missions using Mission Planner software

3D Reconstruction

After performing the flights and acquiring images, a photogrammetry software was used to reconstruct the terrain that was overflown. Agisoft Photoscan software was used to process the images and generate 3D models and digital elevation models (DEM). The 3D models and DEMs of the two regions subject of this study are shown in Figures 7 and 8.

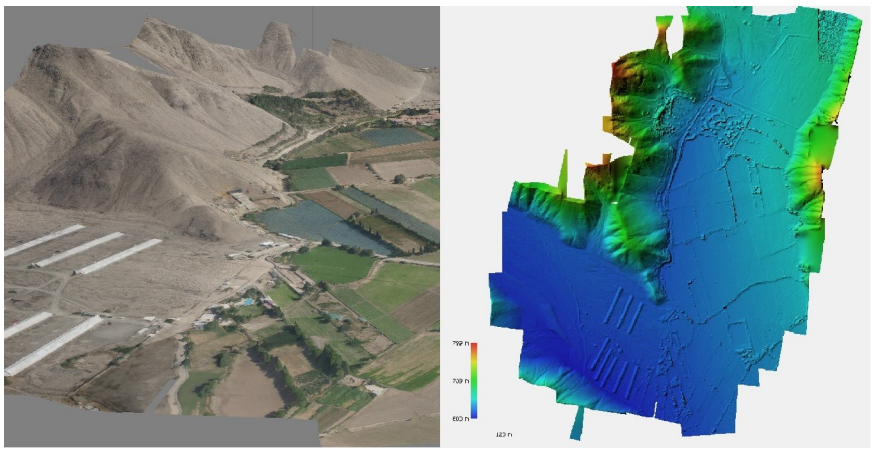


Figure 7. 3D reconstruction – Zone 1, scale 1:500

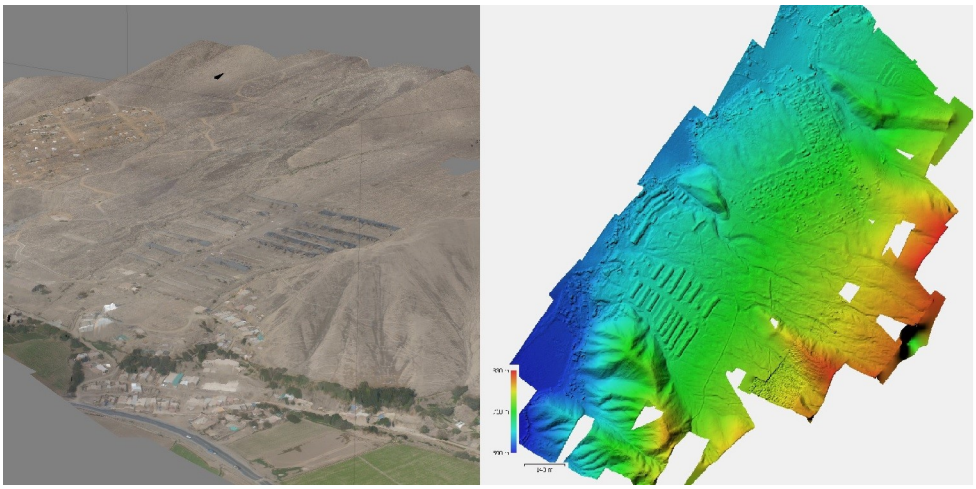


Figure 8. 3D reconstruction – Zone 2, scale 1:1000

Surface flow model

A surface flow model is needed to assess the possibility of a landslide event. It can be obtained by means of processing the Digital Elevation Models obtained from the previous procedure. The D-infinity algorithm, proposed by David G. Tarboron, was implemented using Matlab software for each DEM.

Phase Two: Multirotor Aircraft

The system features a Turbo Ace Matrix-E aircraft frame. It is described as a quadcopter UAV model made of carbon fiber deck which supports a 1000 mm wingspan and it has two main components: one frame consisting of 2 Carbon fiber Structural Beams and 4 15" T-Motor Precision Propellers.

Avionics System

The Avionics System is built around the Naza-M V2 Flight Controller from DJI, whose tasks include the control of all the actuators of the UAV, reception of sensor information for state feedback for the system control algorithm, trajectory planning, signal reception from the Ground RC Controller, among others. For this purpose, the Naza-M V2 Flight Controller uses several important components:

- GPS & Compass Functions include GPS-Lock, Home-Lock, Course-Lock & Return-to-Home.
- Transmitter & Receiver Recommendation: 2.4GHz.
- A RC Receiver, to get the RC signals from a ground controller for manual control of the UAV and to receive the command to start autonomous flight.
- An embedded IMU, for information regarding UAV attitude.
- An embedded barometer, to calculate the pressure altitude over sea level.

Propulsion System

The Propulsion System is responsible for generating the thrust required by the UAV to move forward and control the speed of the aircraft, which is important to generate enough lift during take-off operations. Its main components are 4 Dynamically Balanced Brushless Motors, one 16,000 mAh 25C 6S (22.2V) LiPo Battery and four 40A ESCs with Cooling Algorithm.

Image Acquisition System

A Sony NEX 7 based camera system is used to capture images of 24.3 megapixels. It includes a Gyrox-7+VTX gimbal for camera stability.

Terrain Inspection for Take-Off and Landing Operations

After arriving at the area of operations, the surrounding environment must be inspected to determine suitable terrain for the Take-Off and Landing Operations. A smoother land of minor extension is considered to carry out a successful landing. Take-off operations, although not as difficult as in the fixed wing case, require a place where the ground offers stable footing.

Flight Planning (Trajectory Determination)

Test flights were carried out in the town of Huatocay near Chillón River in Perú (76°59'10.9''W, 11°45'24.7''S) on March 28, 2018. In Figure 3, the flight trajectory for the flying mission over Huatocay is shown. For these flights, a relative altitude of 70 meters was chosen, so to cover the entire town.

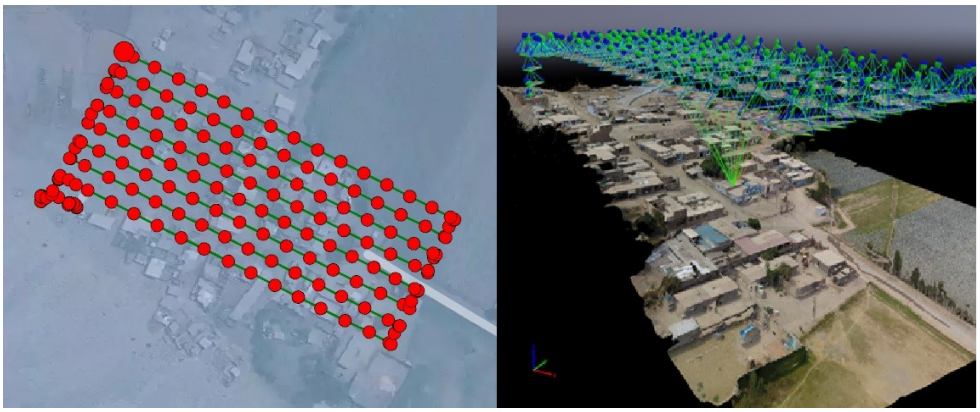


Figure 9. Flight trajectory for 3D reconstruction of Huatocay

3D Reconstruction

After performing the flight and acquiring images, photogrammetry software was used to reconstruct the terrain that was overflown. Pix4DMapper Pro software was used to process the images and generate a 3D model and a digital elevation model (DEM). The 3D model and DEM of Huatocay are shown in Figures 9 and 10.

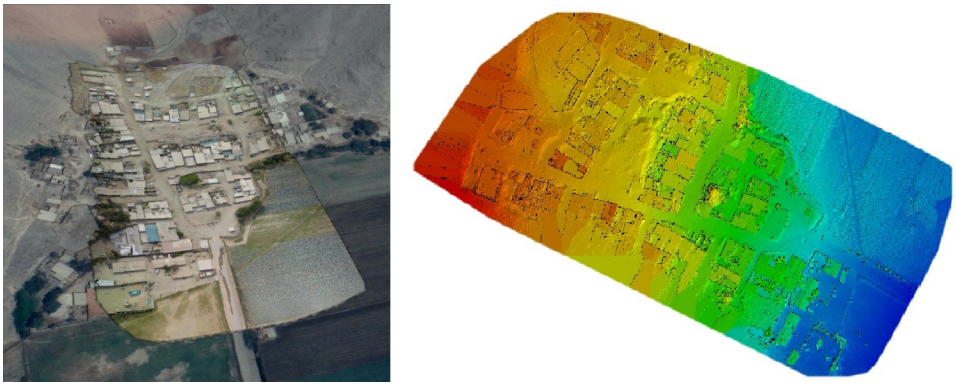


Figure 10. 3D model and DEM of Huatocay

Phase Three: Vulnerability conditions identified

Surface flow model

A surface flow model is needed to assess the possibility of a landslide event. It can be obtained by means of processing the Digital Elevation Model obtained from the previous procedure. The D-infinity algorithm, proposed by Tarboron (1997), was implemented using Matlab software for each DEM. Figure 11 shows the flow model example in red which represent potential landslide to be triggered with critical conditions such as rainfall and type of soil. This model has a close relationship with the landslide events occurred in 2017.

Figure 11. Surface flow models obtained, scale 1:500

DISCUSSION

In this work, we propose the use of Unmanned Aerial Vehicles and Digital Image Processing Software to give additional information for Disaster Risk Management purposes. The combination of these new technologies allows the user to build 3D models, digital elevation models, orthomosaics and other products that can be studied in a GIS. In comparison with traditional methods to obtain this kind of information, such us topography, the use of UAVs and photogrammetry software is a more efficient way because of time, budget and precision. Depending of the type of UAV, the mapping of certain areas can be made in less than the quarter of time spent by traditional methods. Moreover, the cost of conventional method can be three times the cost of UAV based methods (Volkmann, 2017), also using RTK points, the precision reached by the photogrammetry software is in the order of millimeters.

Albeit, the use of UAV and software to process the images possesses some important points to take in consideration. Nowadays, people need a license to pilot these vehicles in many countries, and it expresses some restrictions about the area to fly or other conditions. In addition, not all the kind of UAVs can be used to map specific areas, it requires technical information to plan the autonomous flight. Finally, when the images are acquired, it is required to use a software to build the 3D models and other products. This software is an additional expense and it is also needed to have a basic knowledge of photogrammetry to use them.

For this study, we evaluate this advantages and drawbacks related to these technologies and we are convinced that this methodology should be used because of the continuous development of UAV technology and the availability of them. The municipality of Carabayllo has recently acquired two UAV with the capabilities to map the area of study. Besides, they have been trained to use properly the UAVs, and now they are planning to acquire the license of photogrammetry software to process their images. For these reasons, we consider that this new methodology is a suitable solution to perform aerial mapping for Disaster Risk Management purposes.

CONCLUSION

The results of the information processing allowed to elaborate the susceptibility maps of the area under study, establishing potential area where material flow landslides would occur, the results found allowed to find a correspondence between the information of the affected areas due to of the Coastal Child in 2017 according to SINPAD information and the estimations obtained from the processing of the images shown in the present work.

A new version of this work should include in addition to the degree of slopes a characterization of the territory that includes the levels of risk of the area associated with the characteristics of the type of soil, configuration of the city and amount of rainfall in the study area. It is known in the literature that the landslides and their impact are the result of a more complex system that corresponds to the interaction of all these characteristics, achieving different results according to the state of the criterions, in this way it will be possible to establish at micro level the flow of landslides with more certainty. These categories can also be included considering their historical performance in a cause-effect relationship with the activation of landslides that occurred in the study area.

ACKNOWLEDGMENTS

We thank all authors from PUCP and UNI, to taking part in this first interinstitutional and interdisciplinary research collaboration. Also, we thank Penn University for the seed funding which let the meeting of different background researchers and scholars to run this first collaboration project. Finally, we remark Carabayllo's citizens and authorities participation, who supported and collaborated field work.

REFERENCES

Abdalla, R. (2016) Evaluation of spatial analysis application for urban emergency management, SpringerPlus, 5(1), 2018.

Altay, N., and Green III W. G. (2006) OR/MS research in disaster operations management, European journal of operational research, 175(1), 475-493.

Ayala-Carcedo, F. J. (2002) Mapas de susceptibilidad a los movimientos de ladera con técnicas SIG, Fundamentos y Aplicaciones en España, Instituto Geológico y Minero de España, 7-20.

Chen, T., Zhong, Z., Niu, R. (2018) Landslide spatial susceptibility mapping by using deep belief network Fifth International Workshop on Earth Observation and Remote Sensing Applications (EORSA), 1-5.

Coburn, A. W., Spence, R. J. S. and Pomonis, A. (1994) Vulnerability and risk assessment, UNDP-Disaster Management Training Programme, Cambriage, 2nd edition.

COEN (2017) Informe de emergencia N° 323 - 20/03/2017/COEN, view 7 december 2018, from https://reliefweb.int/sites/reliefweb.int/files/resources/20170321170603.pdf

Cutter, S. L. (2003) GI Science, Disasters, and EmergencyManagement, Transactions in GIS, 7, 439-445.

Esteller, M., Quentin, E. and Díaz-Delgado, C. (2002) Uso de sistemas de información geográfica (SIG) para la determinación de parámetros utilizados en la construcción de mapas de vulnerabilidad de acuíferos, view 7 december 2018, from https://revistas.ufpr.br/hidrogeologia/article/viewFile/2631/2172.

Fernández, T., Jiménez, J., Delgado, J., Cardenal, J., Pérez, J.L., El Hamdouni, R., Irigaray, C. and Chacón, J. (2013) Methodology for Landslide Susceptibility and Hazard Mapping Using GIS and SDI, in S. Zlatanova et al. (eds.), Intelligent Systems for Crisis Management, Lecture Notes in Geoinformation and Cartography, Springer-Verlag, Berlin, Heidelberg.

Hu, K., Chen, M., Duan, S., Teng, Y., Peng, Y. (2016) Research on Management System of Disaster Prevention and Relief Based on Building Information Modeling, International Conference on Information System and Artificial Intelligence (ISAI), 232 – 235.

Ismail-Zadeh, A. and Cutter, S., Eds. (2015) Disaster Risks Research and Assessment to Promote Risk Reduction and Management. ICSU-ISSC, Paris, from http://www.iugg.org/policy/Report_RiskReduction_WCDRR_2015.pdf

Isma'il, M. and Saanyol, I. O. (2013) Application of Remote Sensing (RS) and Geographic Information Systems (GIS) in flood vulnerability mapping: Case study of River Kaduna, International Journal of Geomatics and Geosciences, 3, 618-627.

IWR (2013) Social Vulnerability Analysis: A Comparison of Tools, IWR White Paper, February 2013, from https://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/Social_Vulnerability_Analysis_Tools.pdf

Kumar, Rohan and Anbalagan, R. (2015) Remote sensing and GIS based artificial neural network system for landslide suceptibility mapping, IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 4696 – 4699.

Leiras, A., de Brito Jr, I., Queiroz Peres, E., Rejane Bertazzo, T., and Tsugunobu Yoshida Yoshizaki, H. (2014) Literature review of humanitarian logistics research: trends and challenges, Journal of Humanitarian Logistics and Supply Chain Management, 4(1), 95-130.Manfreda, S., McCabe, M. F., Miller, P. E., Lucas, R., Pajuelo, Mallinis, G., Bem D. E., Helam, D., Estes, L., Ciraolo, G., Mullerová, J., Tauro, F., Isabel de Lima, M., Joao de Lima, L. M. P., Maltese, A., Frances, F., Caylor, K., Kohv, M., Perks, M., Ruiz-Pérez, G., Su, Z., Vico, G. and Toth, B. (2018) On the Use of Unmanned Aerial Systems for Environmental Monitoring, Remote Sensing, 10, 641.

Lewis, J. (2014) The susceptibility of the vulnerable: some realities reassessed, Disaster Prevention and Management, 23(1), 2-11.

Lin, H., Huang, H., Yiming, L., Xiaofei D., Wu Y. (2016) Micro-UAV based remote sensing method for monitoring landslides in Three Gorges Reservoir, China, IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 4944 – 4947.

Manfreda, S., McCabe, M. F., Miller, P. E., Lucas, R., Pajuelo, Mallinis, G., Bem D. E., Helam, D., Estes, L., Ciraolo, G., Mullerová, J., Tauro, F., Isabel de Lima, M., Joao de Lima, L. M. P., Maltese, A., Frances, F., Caylor, K., Kohv, M., Perks, M., Ruiz-Pérez, G., Su, Z., Vico, G. and Toth, B. (2018) On the Use of Unmanned Aerial Systems for Environmental Monitoring, Remote Sensing, 10, 641.

Ministerio de Educación MINEDU. (2015) Programa presupuestal 0068 reducción de la vulnerabilidad y atención de emergencias por desastres (PREVAED), view 7 december 2018, from

http://www.minedu.gob.pe/fenomeno-el-nino/pdf/guia-plan-de-gestion-de-riesgo-2015.pdf.

Muthukumar, M. (2013) GIS based Geosystem response modelling for landslide vulnerability mapping parts of Nilgiris, South India. Disaster Advances, 6, 58-66.

Özdamar, L. and Ertem, M. A. (2015) Models, solutions and enabling technologies in humanitarian logistics, European Journal of Operational Research, 244, 55-65.

Perles, M. and Cantarero, F. (2010) Problemas y retos en el análisis de los riesgos múltiples del territorio. Propuestas metodológicas para la elaboración de cartografías multi-peligros, view 7 december 2018, from http://www.age-geografia.es/ojs/index.php/bage/article/download/1171/1094.

Ramírez, E., Cruz, A., Lagunas A. and Reyes, O. (2013) Uso de vehículos aéreos no tripulados para la caracterización del paisaje sumergido; Bahía estacahuite, view 7 december 2018, from http://www.academia.edu/download/39045133/Uso_de_vehiculos_aereos_no_tripulados_para_la_caracterizacion_del_paisaje_sumergido_Prueba_de_galera.pdf.

Rauld, R., Fock, A., García-Huidobro, F., Letelier, V., Badilla, P., Gallardo, J., Luca, R., Muñoz, L., Cancino, O. (2015) Estudio de peligro, susceptibilidad, vulnerabilidad y medidas de mitigación en la ruta de alta montaña 115-Ch, Paso Internacional Pehuenche, Región del Maule (~ 36 S), Congreso Geológico de Chile, La Serena.

Rodríguez-Espíndola, O., Albores, P. and Brewster, Ch. (2016) GIS and Optimisation: Potential Benefits for Emergency Facility Location in Humanitarian Logistics, Geosciences, 6(2), 18.

Sandholz, M. G. (2018) Natural Hazards and Earth System Sciences, view 7 december 2018, from https://www.nat-hazards-earth-syst-sci.net/18/1233/2018/nhess-18-1233-2018.pdf.

Tanzi, T., Apvrille, L., Dugelay, J., Roudier, Y. (2014) UAVs for humanitarian missions: Autonomy and reliability IEEE Global Humanitarian Technology Conference, 271 – 278.

Tarboton, D.G., (1997) A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models, Water Resources Research, 33(2), 309-319.

Tomaszewski, B., Judex, M., Szarzynski, J., Radestock, Ch. and Wirkus, L. (2015) Geographic Information Systems for Disaster Response: A Review, Journal of Homeland Security and Emergency Management, 12, 571-602.

Volkmann, W. (2017) Small Unmanned Aerial System Mapping Versus Conventional Methods, The Technical Centre for Agricultural and Rural Cooperation (CTA) Working Paper 17/07, May, from https://publications.cta.int/media/publications/downloads/1987_PDF.pdf

UNEP-DHI Partnership, UNEP-DTU, CTCN. (2017) Disaster Risk Assessment using LIDAR, view 7 december 2018, from https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/disaster_risk_assessment_using_lidar.pdf

UNISDR (2009) 2009 UNISDR terminology on disaster risk reduction, available at https://www.unisdr.org/we/inform/publications/7817

Zhao, M. and Chen, Q. (2015) Risk-based optimization of emergency rescue facilities locations for large-scale environmental accidents to improve urban public safety, Natural Hazards, 75, 163-189.

Evaluating the effects of consecutive hurricane hits on evacuation patterns in Dominica

Martin Hilljegerdes
GIScience Research Group, Institute of Geography, Heidelberg University
hilljegerdes@uni-heidelberg.de

Ellen-Wien Augustijn-Beckers
Department of Geo-Information Processing, Faculty of Geo-Information Science and Earth Observation, University of Twente
p.w.m.augustijn@utwente.nl

ABSTRACT

The Caribbean island of Dominica is at constant risk of being hit by tropical storms during the hurricane season. Therefore, Dominica and areas in similar situations need to raise their resilience to natural hazards. The potential consequences of climate change intensify this risk. After a hurricane hit, repair of damage to buildings and infrastructure can take several months. As hurricane frequency is increasing and time between hurricanes fluctuates, modeling sequences of hurricane events can help to determine different evacuation strategies. This paper introduces an agent-based model, simulating two hurricane events in one season. The prototype simulates the movement of evacuees over a road network and damage to buildings and infrastructure. Initial results show marked differences between road movements of evacuees during a second evacuation. Although shifts in the average shelter occupation are small (up to 2%) for our case study, this can indicate that adjustments to shelter capacities are necessary.

Keywords

Agent-based modelling, evacuation simulation, multi-event scenario, NetLogo, OpenStreetMap

INTRODUCTION AND BACKGROUND

Natural hazards like tropical storms and hurricanes pose a permanent risk to many regions and their population. They can cause a direct threat to life, destruction of homes and basis of life, a breakdown of the economy or the outbreak of diseases in the aftermath and more. Depending on the location, the exposure of a population towards natural hazards varies, as well as the preparedness and the resilience of a society towards a potential catastrophe (Lam et al. 2014). Small island states in the Caribbean have a high exposure to natural risks, especially to tropical cyclones and their strongest category: hurricanes. In addition to this, many countries in the Caribbean have limited resources and are vulnerable, yet not resilient to the impacts of those risks (Jetten et al. 2014).

In the Atlantic Hurricane season of 2017, 17 named storms affected Central America and the South-Eastern States of the USA (Shultz et al. 2018). Among those storms, ten developed into hurricanes. Hurricane Maria was a category five hurricane, passing directly over the island of Dominica, and affecting other islands as well. Being hit directly by the hurricane, the destructions on Dominica were disastrous. Thirty-one people died during the event, and a considerably larger number of people were severely injured (ACAPS 2018). Houses were destroyed, as was the majority of the island's infrastructure. While this event alone revealed the danger the people of Dominica are exposed to, the effects of climate change might lead to even more severe tropical cyclones and hurricanes in the future (Lam et al. 2014). As more tropical cyclones will eventually develop into hurricanes, an increase of the number of hurricanes per season can be expected too (Knutson et al. 2010).

Therefore, it is necessary to increase the preparedness and resilience of the island and its population. This is supported by an ongoing shift from an ex-post response and recovery to an ex-ante approach with a focus on minimizing the disaster risk by reduction of vulnerability, capacity building and better information and institutional strengthening. The planning and organization of shelters and evacuation routes in case of an

emergency are crucial (World Bank 2012). To optimize shelter and route planning, estimations of the population's behavior and their resulting movement in case of evacuation are needed. Due to the impacts of climate change, it is likely, that in the near future multiple high category events occur in one season, affecting the same island. Roads and bridges, previously designed to be part of an evacuation route, may be impassable and the recovery time between storms might not be sufficient to allow for reconstruction. The planning authorities and other responsible bodies need to be aware of these circumstances.

Having limited resources and capacities, the island of Dominica and its authorities need methods to be developed to help to raise resilience to catastrophes (Lam et al. 2014). Agent-based modeling offers great potential for simulations of such events and generates valuable information. The concept of agent-based modeling tries to simulate a system by representing its individual components and behaviors. In agent-based models, "individuals or agents are described as unique and autonomous entities that usually interact with each other and their environment locally" (Railsback and Grimm 2012, p. 10). Thereby it can be analyzed how the system's behavior is constituted by the characteristics and behaviors of its individual components.

There has been extensive research in the field of agent-based modeling in evacuation contexts. Chen et al. (2006) created a model for hurricane evacuation in the Florida Keys. The focus was put on the clearance time of the entire area and on how many residents would need accommodation once the route became impassable. Liu and Lim (2016) developed a simulation model for the 2011 Brisbane flood, concentrating their research on shelter assignment and routing strategy, and thereby integrating GIS-based spatial analysis. Focusing on the interactions among evacuees during an evacuation process, Zhang et al. (2009) analyzed how different behaviors of agents during the process may change the overall movement in the network. Furthermore, D'Orazio et al. (2014) designed an agent-based model approach for simulating pedestrians' evacuation in urban outdoor scenarios by analyzing videotapes of real events.

What most of the studies share is that they either focus on motorized traffic simulation, or on building or urban (public places / events) evacuation. Moreover, clearance of the affected area is often the focus of other evacuation simulations. Compared to the former-mentioned studies, this study differs as it is not possible to clear the affected area and most people evacuate via walking. Being a Caribbean island, Dominica is cut off once the hurricane hits the island. Additionally, in this study infrastructure disturbances are simulated in a multi-event scenario (two events in one season) to detect differences in shelter occupation and evacuation routes, and the resulting movement patterns, which makes the approach deviate from other comparable evacuation simulation concepts.

The main objective is to develop a system that facilitates the combined analysis of infrastructure disturbances, especially road damages, and evacuation behavior for planning purposes. It aims to do so by creating a prototype model that integrates both, infrastructure disturbances and people's behavior in evacuation events. How can agent-based modeling with an integration of a multi-event scenario based on a road network be used to improve preparedness to hurricanes in Dominica?

APPROACH, METHODS, MODEL

Model Concept and Implementation

The model's purpose is to simulate the movement of evacuees during different phases of two consecutive storm (hurricane) events and to integrate road damages done by the first storm for the following event, influencing and potentially altering the movement and shelter allocation. The phase between the events is not simulated explicitly.

The model consists of three phases per event. The phases are as follows: 1) Evacuation phase: population moving to shelters, 2) Hurricane phase: hurricane taking place, population in shelters, damages are occurring, 3) Post-hurricane phase, population returning home. The phases are repeated for the second event under different circumstances (i.e. road network affected by damages). Additionally, one phase between both blocks represents the time between two events, meaning that the population is at home, after the first event (Figure 1, Table 1). The time steps (ticks) are defined as seconds during the evacuation and the return home phase of the model run. The moment in time when the hurricane takes places, and the exact duration of a hurricane evacuation, are not simulated. Neither is the time in between two hurricanes. This is because we are simulating differences in road movement and shelter occupation rather than evacuation time.

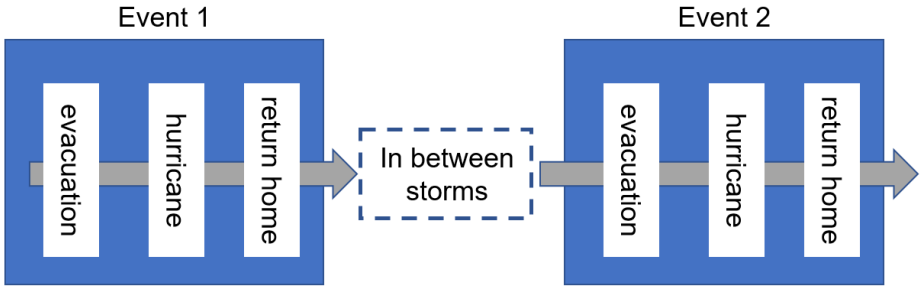


Figure 1. Schedule of the model concept and the corresponding phases per event

Table 1. Model concept phases and the corresponding actions in the simulation

Event	Phase	Concept	Actions
1	1	Evacuation phase	Households moving to shelters
	2	Hurricane phase	Households in shelters, Hurricane active, damages to roads
	3	Post-hurricane phase	Households returning home
-	4	In between events	Households at home
2	5 to 7	Repetition of 1 to 3	Repetition of 1 to 3
-	8	Post-hurricane phase	Households at home, Simulation finished

1. Evacuation phase

The evacuees are aggregated to households. At initialization, each household is assigned a building as a home. Households calculate the optimal route from their starting location to all shelters and know which shelter is the closest, based on the distance of the routes, and will always try to go the nearest shelter (Figure 2). From the home node, the distance to each shelter node is calculated, based on the optimal route and the weight value of the links (length of roads between nodes). The network extension in NetLogo 6.0.4 (Wilensky 1999) is able to find the best route using the Dijkstra algorithm, comparing different options on the network and choosing the one with the least sum of weight (distance) values (Dijkstra 1959). The distances to all shelters are compared, and the shelter node of the shelter with the least distance is defined as the destination for the household agent. The path from the home node to the destination node is now stored as an ordered list variable of the household agent, containing all links (edges). Also, all nodes along the route are stored as an ordered list. The list of nodes will be used for the movement, following node by node on the path. Once the first evacuation starts, all households start their movement at the same point of time without hesitation and without decision making of whether or when to evacuate. They move over the road network at a constant walking speed of 1.4 meters per second (Mohler et al. 2007) until reaching the destination and the list of nodes to visit is empty.

2. Hurricane phase

Once all household agents have arrived at their destination, the damage-to-nodes procedure starts, making road nodes die with a probability based on the risk zone class they are located in. The procedure uses the patches (pixels in NetLogo logic) own variable of the risk-zone-class for a probability for a node to die if it is located on the patch. On a patch with the highest value of the risk class (3), there is a risk of 10% for a node to die, 3% on a patch with a risk class of 2, and 1% on a patch with a risk class of 1. The values are an approximation based on the work with landslide and flood hazards of Jetten et al. (2014) in the CHARIM project. The CHARIM project aims to support the generation and application of landslide and flood hazard risk in the Caribbean region. Some nodes on the road network are defined as the home node for households. These can also be affected by the damage-to-node procedure. If a home node dies, it is assumed that the home of the household was destroyed. The household will then stay in the shelter.

3. Return home phase

After the hurricane phase, households will return to their home locations. The calculate-path-home procedure calculates the best way home. This does not necessarily have to be the inverse of the route the household has taken to the shelter, as the road network may have changed due to the previously mentioned damage-to-nodes procedure. If a household cannot find a path leading to their home location, which may occur if all connecting roads were destroyed, they stay at the shelter. When all household agents arrived at their home location, the steps are repeated. However, the road network will stay altered, representing the damages done by the hurricane in the second phase. The route calculation of the households in the next evacuation phase takes these changes into account.

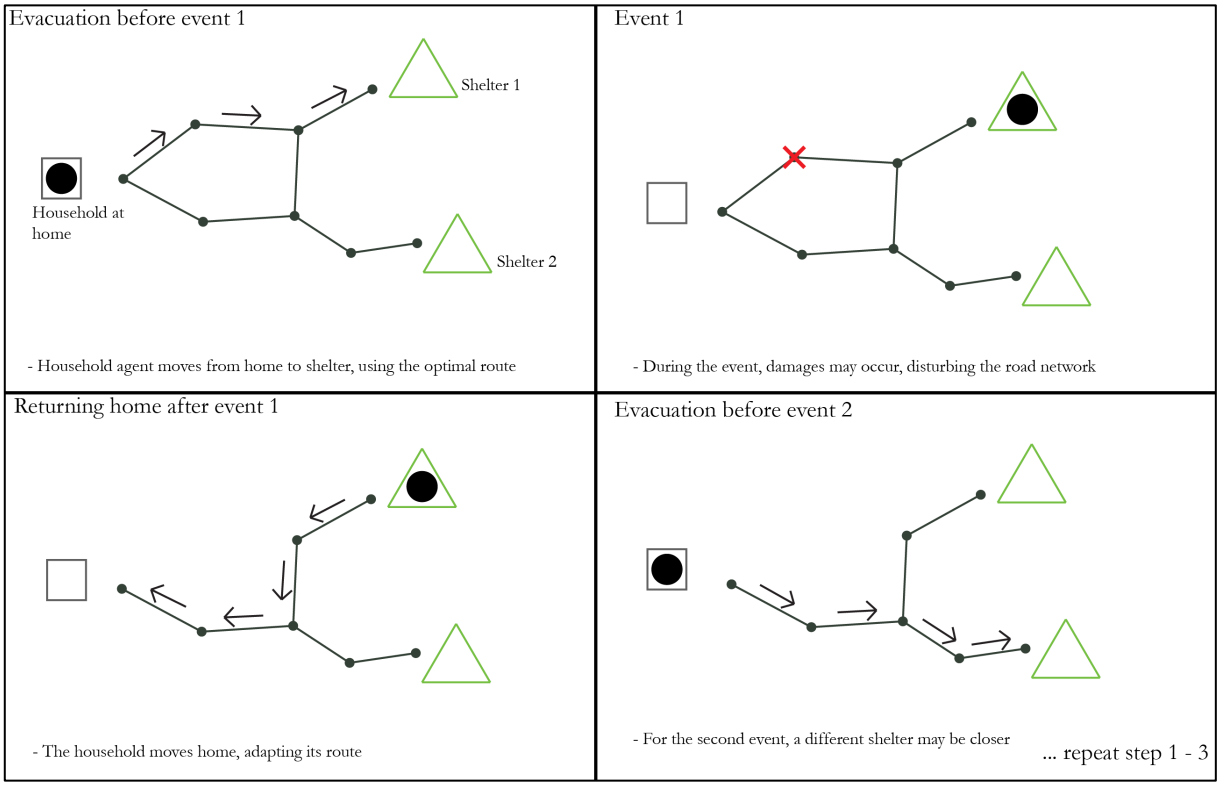


Figure 2. Logic of routing procedures based on Dijkstra algorithm. Depending on the phase, the road network can be affected and altered through damages

Study Area and Data Description

The prototype model will be tested on Roseau, the capital of Dominica. This area has a relatively dense population with a good road coverage, multiple shelters, and potential damage to infrastructure (Figure 3). The number of household agents in the model should reflect the population of the study area. Five thousand households is a realistic number, considering the population of Roseau (14.725) (Commonwealth of Dominica 2011). This is supported by the number of potential dwellings in the study area (5030), after data editing. For this study, the following data is needed: roads, buildings, the location of shelters and areas of potential risk (damage).

Roads and buildings

OpenStreetMap (OSM) data was used for retrieving data on the street network and building locations, using the OSM keys “highway” for streets and “building” for buildings. The Humanitarian OpenStreetMap Team (HOT) carried out an activation (actively pursuing the creation of map data with the help of volunteers in response to a crisis) for data improvement, reacting to the disaster caused by Hurricane Maria. It aimed to improve the buildings and road data coverage by performing multiple projects in the Caribbean, including one explicitly for Dominica (OpenStreetMap contributors 2018).

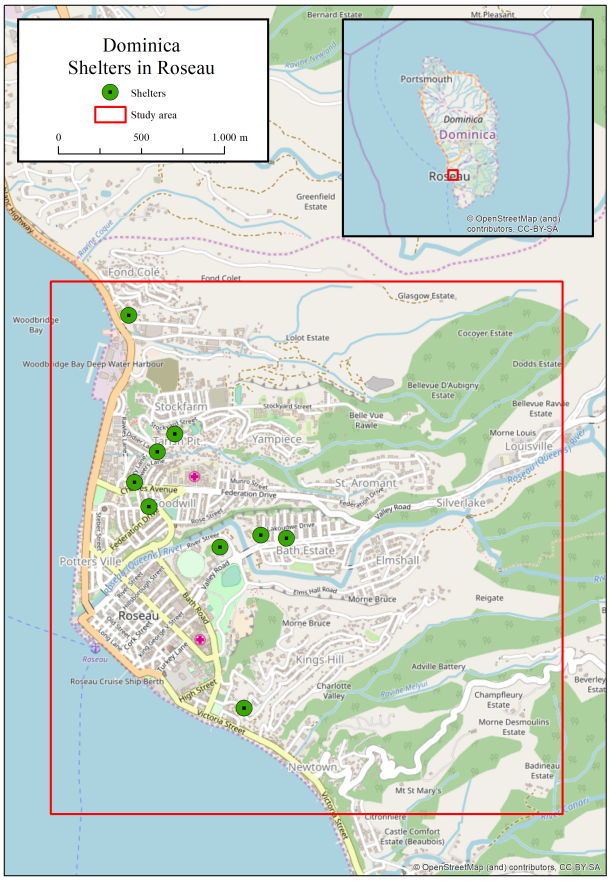


Figure 3. Study area (Roseau) and location of shelters

For the methodology of this study, it is advantageous to have a relatively high number of nodes for the road network, as the nodes are used for the placement of the agents, for defining road damages and for route calculation. Thus, long segments without nodes were edited manually, adding more nodes and splitting the segment into multiple parts.

Buildings were identified as residential (dwellings) or non-residential based on building size (area). To exclude non-residential buildings, only those larger than 20m² and smaller than 300m² were kept as potential dwellings. The selection of these values is partially arbitrary, as no more information (e.g. attributes of buildings data) is available for the study area.

Some of the buildings represent hurricane shelters. The data about locations of hurricane shelters in Dominica was downloaded from the GeoNode data-sharing platform of the Caribbean Handbook on Risk Information Management (CHARIM) project (Jetten et al. 2014). Nine shelters are defined in the respective study area of the city Roseau and surroundings.

Risk zones

For estimating the probability of road damage during a hurricane event, road damage risk zones have been created based on flood-risk and landslide susceptibility, classified within the CHARIM project. Combining both raster datasets and reclassifying the combinations, three classes of potential risk zones were defined (Table 2, Figure 4). A classification value of 1 means a relatively low chance of a road being damaged, a value of 3 a high probability.

Table 2. Risk zone definition: Reclassification of a combination of flood hazard and landslide susceptibility datasets, resulting in three classes of potential risk (1 – low chance of a road being damaged, 2 – medium, 3 – high)

		Flood hazard extent				
		None	1:50 year rainfall	1:20 year rainfall	1:10 year rainfall	1:5 year rainfall
Landslide susceptibility	Low	0	1	1	2	3
	Medium	1	2	2	2	3
	High	3	3	3	3	3

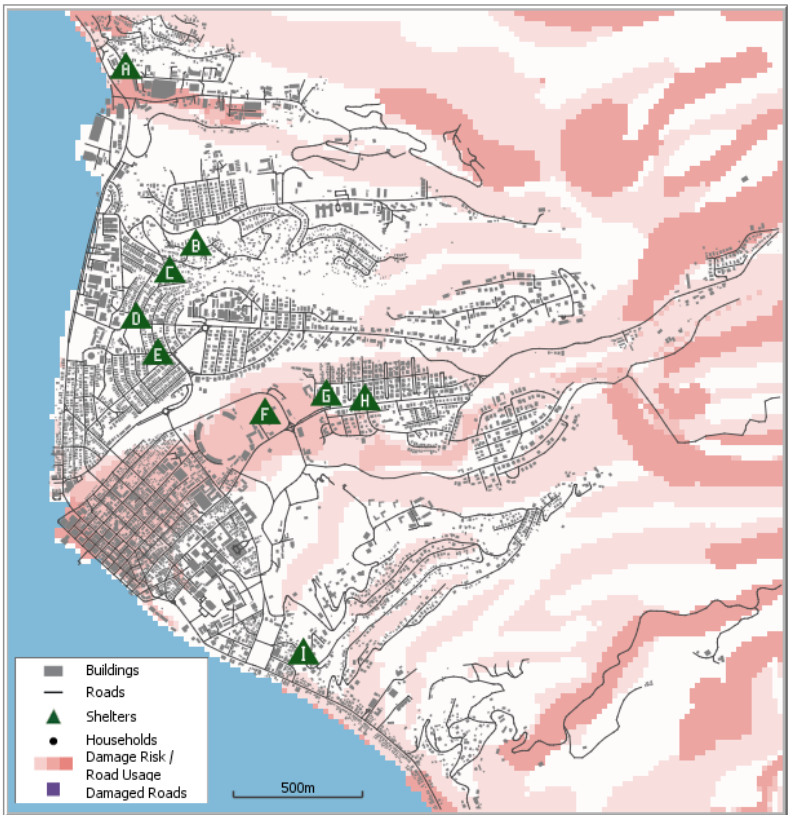


Figure 4. Overview of integrated data: Risk zones, buildings and roads

Model output and experiments

The described conceptual model was implemented in, and the described geodata was imported into the NetLogo 6.0.4 software. Experiments with multiple simulation runs were conducted. Two types of model output are defined to evaluate the model performance: the number of evacuees in each shelter during the hurricanes and the movement pattern of the evacuees during evacuations. As two consecutive events are simulated in each simulation run, we can determine the difference in shelter occupation and road network use between the two events.

A counter procedure was defined to detect differences in the movement pattern of evacuees as a result of a changed road network. Each patch has a counter variable, counting the number of households located on the patch at each time step during the evacuation phases. These counter values lead to a pattern, which can be interpreted as a relative usage of the roads. For both events, one individual counter exists and thereby allows the comparison of road usage (and route choices) in the evacuation phase.

Additionally, the number of households per shelter for each hurricane event is tracked. The comparison of shelter occupation reveals a possible over-occupation (above the available space) and changes in occupation between two events. The combined observation of relative road usage and numbers of evacuees per shelter will allow a first interpretation of the influences of road damages on movement patterns and shelter allocation.

As the procedure of road damages, i.e. nodes dying during the hurricane phase, includes a probability based on the predefined risk zones, the patterns of damages will be different for each simulation run. To assess the influence of the stochastic elements, the simulation was run 100 times with the same setup. Observing the development of the average number of road damages in the first event, the variation of the resulting values is relatively stable after 25 runs (Figure 5).

For those 25 runs, the values for road usage (counted households on a patch) for the first event without road damages and the second event including road damages are compared by computing the difference between the events for each model run. The average of those differences is calculated and visualized. Furthermore, the average number of household agents per shelter for both events is calculated.

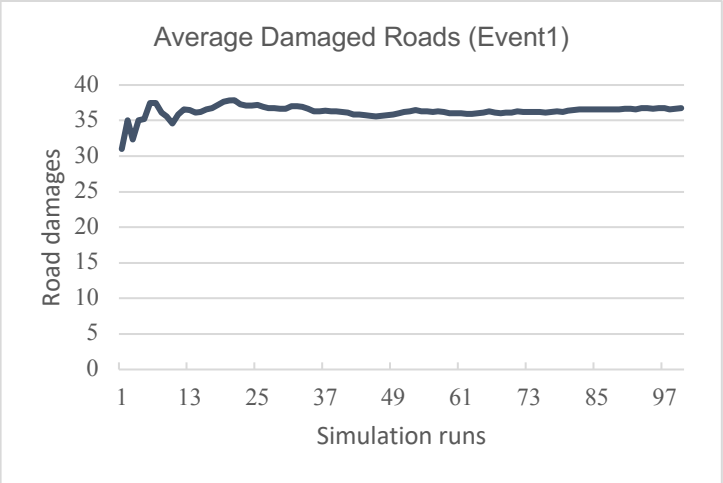


Figure 5. Average damaged roads during the first event after a number of runs

RESULTS AND DISCUSSION

In this study, it was examined how road damages caused by storm events would affect the movement of evacuees, changing their route choices and thereby influencing the shelter allocation. Results for the movement pattern (Figure 6) show that changes are mainly occurring on main roads running in an east-western direction and that the difference in road usage between the two hurricane events is considerable. This can be interpreted as an effect of the combination of the high number of households living in the area, the damage caused to these roads, and the fact that multiple shelters are located along the main roads.

The interplay of shelter allocation to shelter E, F, and I is of main interest for the interpretation of the results. On the route leading from the southwest to shelter F road damages frequently occur, making the road inaccessible in many runs. Additionally, alternative routes around shelter F are commonly damaged. This leads to an increase of road usage from the respective area on a route north towards shelter E, and south towards shelter I. Another interesting aspect is the movement from the eastern outskirt settlement, being connected by one road only to shelter H. Damages that occur here, make movement between the settlement and the shelter impossible, leaving a high number of households in need to stay at the shelter. Consequently, the road usage towards shelter H is reduced. Furthermore, roads leading to shelter I (at the coast from the southeast and from the inland from the northeast) are frequently damaged. Therefore, the adjacent roads are being used as alternative paths in many runs, explaining the substantial increase of usage.

Another interesting fact is the average number of households per shelter for both events (Table 3). Due to the road damage issues explained before, the average percentage of households seeking shelter in shelter F reduced by 2%. At the same time, the number of households in shelters E and I increased by 1.4% and 1.1%. As the eastern road to shelter H is frequently being damaged and inaccessible, a slight reduction of the average shelter allocation in shelter H can be observed (0.5%). If a household cannot find a path back home in the return home phase, it needs to stay in the shelter. As the numbers of Table 2 reveal, these numbers differ among the shelters. Especially the shelters F (115.5), H (81.4) and I (128.7) show relatively high average numbers of stuck households. These shelters are connected to some residential areas by a single road only and lack alternative routes. Therefore, they host a high average number of households, which cannot return home.

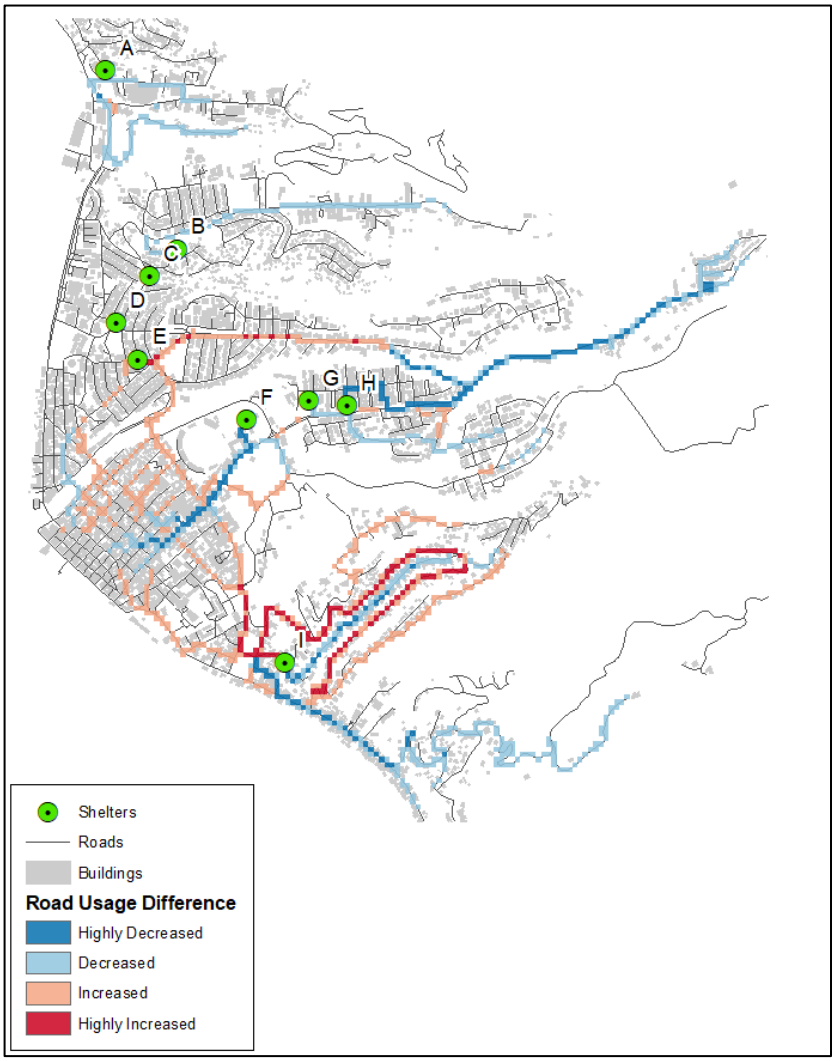


Figure 6. Average difference in road usage between event 1 and event 2 (during evacuation phases)

Table 3. Average shelter occupation per event per shelter

	Event 1		Event 2			
Shelter	**Number of households**	**Percentage of total households**	**Number of households**	**Percentage of total households**	**Tendency**	**Households staying in shelter**
A	281	5.7	277	5.6	=	51.1
B	717	14.6	717	14.6	=	10.9
C	106	2.2	110	2.2	=	4
D	222	4.5	222	4.5	=	0
E	1192	24.2	1258	25.6	↑	34.4
F	573	11.6	471	9.6	↓	115.5
G	247	5	245	5	=	14.8
H	394	8	373	7.5	↓	81.4
I	1191	24.2	1244	25.3	↑	128.7

The changed road usage and route choices for a second evacuation event, depending on the damages occurring during the first event, deliver valuable information about critical road segments and sections. If a shelter is connected to a highly populated area by a limited number of roads, and if these roads are at risk of being disturbed, the movement pattern of the evacuation changes. Using this information, planners can identify critical road segments and plan road fortifications or define alternative routes leading to the corresponding shelter. Additionally, prioritization of road reconstruction can be done. The information provided by the model might lead to the realization that the location of a specific shelter is unsuitable, as the risk of it becoming inaccessible is high.

Furthermore, the results of the model run revealed, that a disturbed road network leads to changes in the numbers of people (or households) per shelter. The model results and the derived information can be used for evaluation of shelter allocations. One effect may be that if a shelter is not accessible for a second evacuation, other shelters in the area are used by a larger number of evacuees. By using a model that takes this into account, the planner is able to prepare and avoid an unexpected over-occupation of a shelter. Also, a shelter might be cut off from the network, preventing evacuees to return home, as the roads leading back to populated places and settlements are not usable anymore. To be prepared for this, shelters, which are identified as being at risk of inaccessibility after one event, and that therefore need to house evacuees for a longer time, need to stock up their supplies or alternative shelter locations should be defined.

CONCLUSION AND FUTURE WORK

In the course of this study, a prototype agent-based model was created, combining disturbances of infrastructure and the evacuation movement of the population in the case of two consecutive hurricane events on the island of Dominica. The prototype makes use of a multi-event scenario and a network-based routing systematic. Initial runs of the simulation model revealed that damages to infrastructure have a significant influence on the movement patterns and route choices of the population, leading to changes in the road usage and shelter allocations.

Multi-event modeling can be used to find critical road segments and problematic shelter locations. This can give planners a tool that can help to take measures to improve the preparedness for hurricanes. The current prototype has some limitations, as it assumes that all people evacuate and that all evacuees select the nearest shelter as destination. This is not true, as people may decide to stay home or evaluate the safety of the shelter and select a different one based on multiple criteria. A more advanced evacuee behavior model can be integrated in the prototype to simulate the number of evacuees, and the route and shelter choices they make, using more advanced mechanisms (e.g. artificial intelligence).

The model should be tested for other areas in Dominica or other Caribbean islands and more detailed analysis can be done on the simulation results, e.g. by examining individual routes of evacuees to gain a better understanding of the evacuation behavior. The simulation phase in between the two hurricane events can be filled. During this period, road repairs can be conducted. By varying the length of the repair period, a more realistic picture can be obtained about the consequences of multiple hits. Also, it is possible to simulate more than two events in one simulation. Further tests should be conducted in this regard. The risk of road damage for the different areas can be calibrated by analyzing previous hurricane events (e.g. by using remote sensing technology). The current risk function combines two different causes: landslide and floods. These two hazards could also be separated to come to a better risk prediction.

The integration of more data, e.g. attributes of the population, building types, road surfaces etc., can lead to further details. However, the quality and availability of data should be evaluated first. As the road network, derived from OpenStreetMap, is of crucial importance for the model, specifically this data should be assessed more in future work before extending the model. Using intrinsic quality measure based on the analysis of the historic development of OpenStreetMap data could be an option (Auer et al. 2018). The model concept and its results should be validated, once the development of the model has advanced further. Sensitivity, uncertainty and robustness analysis need to be performed to test the quality of the simulation. There are several elements, which could be evaluated. By analyzing satellite or aerial images taken shortly after a hurricane occurred, the road damage function of the model could be adapted to represent a realistic damage pattern. Another option could be to compare the occupation rate of the shelters during real evacuations with the simulated occupation rate.

In general, future research need to be conducted for multi-event and routing based concepts. The implemented prototype and its applicability should be developed and assessed further, striving for a more complete and realistic model. This could finally lead to important information and insights to improve the planning of evacuation events and beyond. Further interpretation of the results, potentially with direct exchange of ideas with decision makers, should be considered. Additionally, extensive user research, such as user requirement and usability studies, also taking visualization options into account, are required to support the further development of the model concept and its implementation.

ACKNOWLEDGMENTS

The work is based on a master thesis, conducted and written at the Faculty of Geo-Information Science and Earth Observation of the University of Twente, in context of the International Erasmus Mundus Joint Master Degree (EMJMD) of Master of Science in Cartography, coordinated by the Technical University of Munich. It is supported by the Klaus Tschira Foundation (KTS), Heidelberg, and the Erasmus Mundus Master Course Scholarship. We thank the anonymous reviewers for their valuable suggestions and feedback.

PUBLICATION BIBLIOGRAPHY

ACAPS (2018): Dominica: The impact of Hurricane Maria. Disaster Profile. Assessment Capacities Project. Available online at https://reliefweb.int/report/dominica/dominica-impact-hurricane-maria-disaster-profile-january-2018.

Auer, Michael; Eckle, Melanie; Fendrich, Sascha; Griesbaum, Luisa; Kowatsch, Fabian; Marx, Sabrina et al. (2018): Towards Using the Potential of OpenStreetMap History for Disaster Activation Monitoring. In : 15th International Conference on Information Systems for Crisis Response and Management. ISCRAM 2018. Rochester, NY, USA.

Chen, Xuwei; Meaker, John W.; Zhan, F. Benjamin (2006): Agent-Based Modeling and Analysis of Hurricane Evacuation Procedures for the Florida Keys. In *Nat Hazards* 38 (3), pp. 321–338. DOI: 10.1007/s11069-005-0263-0.

Commonwealth of Dominica (2011): 2011 Population and Housing Census. Preliminary Results. Central Statistical Office, Ministry of Finance. Roseau, Commonwealth of Dominica. Available online at http://www.dominica.gov.dm/cms/files/2011_census_report.pdf.

D'Orazio, Marco; Spalazzi, Luca; Quagliarini, Enrico; Bernardini, Gabriele (2014): Agent-based model for earthquake pedestrians' evacuation in urban outdoor scenarios: Behavioural patterns definition and evacuation paths choice. In *Safety Science* 62, pp. 450–465. DOI: 10.1016/j.ssci.2013.09.014.

Dijkstra, Edsger. W. (1959): A note on two problems in connexion with graphs. In *Numer. Math.* 1 (1), pp. 269–271. DOI: 10.1007/BF01386390.

Jetten, Victor G.; Alkema, Dinand; van Westen, Cees. J.; Brussel, Mark J. G. (2014): Development of the Caribbean handbook on disaster risk information management : extended abstract. Abstract from Analysis and management of changing risks for natural hazards.

Knutson, Thomas R.; McBride, John L.; Chan, Johnny; Emanuel, Kerry; Holland, Greg; Landsea, Chris et al. (2010): Tropical cyclones and climate change. In *Nature Geosci* 3 (3), pp. 157–163. DOI: 10.1038/ngeo779.

Lam, Nina S.-N.; Arenas, Helbert; Brito, Patricia L.; Liu, Kam-Biu (2014): Assessment of vulnerability and adaptive capacity to coastal hazards in the Caribbean Region. In *Journal of Coastal Research* 70, pp. 473–478. DOI: 10.2112/SI70-080.1.

Liu, Xuefen; Lim, Samsung (2016): Integration of spatial analysis and an agent-based model into evacuation management for shelter assignment and routing. In *Journal of Spatial Science* 61 (2), pp. 283–298. DOI: 10.1080/14498596.2016.1147393.

Mohler, Betty J.; Thompson, William B.; Creem-Regehr, Sarah H.; Pick, Herbert L.; Warren, William H. (2007): Visual flow influences gait transition speed and preferred walking speed. In *Experimental brain research* 181 (2), pp. 221–228. DOI: 10.1007/s00221-007-0917-0.

OpenStreetMap contributors (2018): 2017 Hurricanes Irma and Maria. Edited by OpenStreetMap Wiki. Available online at http://wiki.openstreetmap.org/w/index.php?title=2017_Hurricanes_Irma_and_Maria&oldid=1586808, checked on 13 February.

Railsback, Steven F.; Grimm, Volker (2012): Agent-based and individual-based modeling. A practical introduction. Princeton: Princeton University Press.

Shultz, James M.; Kossin, James P.; Shepherd, J. Marshall; Ransdell, Justine M.; Walshe, Rory; Kelman, Ilan; Galea, Sandro (2018): Risks, Health Consequences, and Response Challenges for Small-Island-Based Populations: Observations From the 2017 Atlantic Hurricane Season. In *Disaster medicine and public health preparedness*, pp. 1–13. DOI: 10.1017/dmp.2018.28.

Wilensky, Uri (1999): NetLogo. Version 6.0.4. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL. Available online at http://ccl.northwestern.edu/netlogo/, checked on 2/14/2019.

World Bank (2012): Disaster risk management in Latin America and the Caribbean Region : GFDRR country notes (English). World Bank. Washington, DC.

Zhang, Bo; Chan, Wai Kin; Ukkusuri, S. V. (2009): Agent-based modeling for household level hurricane evacuation. In Ann Dunkin (Ed.): Winter Simulation Conference. 2009 Winter Simulation Conference (WSC 2009). Austin, TX, USA, 12/13/2009 - 12/16/2009: Winter Simulation Conference (ACM Digital Library), pp. 2778–2784.

Instagrammers report about the deadly wildfires of East Attica, 2018, Greece: An introductory analytic assessment for disaster management purposes

Stathis G. Arapostathis
Geographer, PhD graduate
Harokopio University
e.arapostathis@gmail.com

ABSTRACT
This article contributes to identifying the capabilities of Instagram when utilized as a source of Volunteered Geographic Information (VGI) for disaster management (DM) purposes. The geographic focus of this research is in the Mediterranean area. As case study, the fire event of East Attica 2018, Greece, was chosen. This major fire occurred on the 23rd of July 2018 and caused the death of 100 people, the injury of additional 164 while the total burnt area was about 1275,9ha. It is the deadliest in modern Greece's history and the second deadliest at a global level, within the 21st century. About 15000 related photos along with the corresponding captions and timestamps were crawled from Instagram. An initial sample of about 1100, was analyzed, by using a certain methodology divided in certain steps, the most important of which include the classification of the information to certain categories, geo-referencing and the creation of graphs and maps that visualize the processed data.

Keywords
volunteered geographic information (VGI), Instagram, social media, fires, disasters, disaster management

INTRODUCTION

There is over a decade passed since the notion of Volunteered Geographic Information (VGI) emerged from Goodchild (2007) and many scientific teams are now at the of stage researching the potentials of this phenomenon in a variety of sciences. VGI is the act of having normal citizens, without any related scientific background, produce geographic information or information with spatial extension, either intentionally or unintentionally. One of the most important applications of VGI focus on disaster management (DM). A plethora of research articles have analyzed various aspects of the potentials of VGI in disaster management, some of them are mentioned indicatively in the following paragraphs.

The work of McDougall (2011) focuses on the effectiveness of social media for providing additional insights in the flood events of Queensland floods in Australia. Those major floods affected a huge geographic area consisted of 30 cities and agricultural areas while, in terms of budget, the restoration cost was about five billion dollars. The most important conclusion of the researcher was related to the immediacy and depth of information that is provided through social media, conclusion that is also verified by Yin et al. (2012) who stated that by using this information, the relevant authorities can improve their awareness and as a result the response in emergency situations. Yin et al. (2012) also developed a system for manipulating the extracted information. Regarding fire events, previous research demonstrates some recent work about the social media network twitter and the fire event of North-East Attica that occurred in Greece during the summer of 2017 (Arapostathis and Karantzia 2019).

VGI research is not only limited on processing data of existing VGI sources but also include various participatory activities like the approach presented by Rahman et al. (2018). That approach is related to the development of a community was able to identify spots of the Dhaka city in Bangladesh, that were vulnerable to earthquakes. The community handled the development of strategies for reducing the vulnerability along with the execution of these related actions. A similar approach is presented by De Brito et al. (2018) and is related to the development of an expert community who was involved in defining the criteria that emerge a geographic area as vulnerable in the

event of a flood.

Especially regarding social media, there is a logical trend of combining various social media sources or even social media sources with satellite imagery in order to extract a more complete output (de Albuquerque et al. 2015; Morstatter et al. 2013). Another nice combination of data source is presented in the work of Smith et al. (2012) who combined social media data and data gathered from a graphics processing unit (GPU) in the case study of the Tyne and Wear floods that occurred during June and August 2012 in the United Kingdom. Those approaches are rather the most effective ways towards perfection. However, futher research is vital to be performed for each social media network exclusively, using case studies that vary geographically in order to have the most comprehensive assessment regarding the comparative potentials of each social media source when is utilized as a VGI source for DM purposes. Especially regarding geographic variations, one of the most important characteristics of user generated content is the ubiquitous and anarchic production in terms of volume, volunteers and geographic areas (Girres and Touya 2010; Haklay et al. 2010).

According to author's opinion the main open challenges, regarding the manipulation of social media datasets, are clustered in four certain categories, all transpired by the significant notion of quality. The first cluster is related to defining the appropriate classification structure for the processed information, suitable for each disaster event category according to the semantics and data properties of each VGI source. There are many articles of various respectful researchers that propose various structures either while researching certain case studies or by creating various conceptual frameworks (Albuquerque et al. 2015; Fahrer et al. 2018; Arapostathis et al. 2018; Dashti et al. 2013). However, as research in the field is constantly evolving, there should be a common definition regarding the most appropriate one.

The second cluster of challenges is related to the geo-referencing of information. Accurate and precise geo-referenced information can lead to the rapidness of the actions taken regarding response during a disaster management situation. However, this is not always feasible. The most desired outcome would be to have a precision level of few meters or even of few centimeters. Some of the DM stakeholders though, may be interested in having information displayed in other scales.

The third category of challenges is related to developing the appropriate techniques for visualizing information that makes sense to all DM participants. From the decision makers, up to simple volunteers which are trying to contribute to the way they can. Taking this into consideration, the graphs and maps used should be very simple and easily readable in few seconds despite of the educational background of each individual.

Finally, the fourth cluster of challenges is related to automation of the methodologies producing the desired output in real time. Analyzing data coming from VGI sources, such as social media, is a time-consuming process as many researchers conclude (Imran et al. 2013, Zhong et al. 2016, Grunder-Fahrer et al. 2018).

Current status of this research aspires to make a step further towards the first three categories.

CASE STUDY

The wildfires of East Attica 2018, Greece, started within the 23rd of July 2018, at 18:41 local time. Main affected areas were the areas of Mati, Marathonas, Rafina, Nea Makri, and the east side of the Penteli mountain. A hundred people died while 164 were injured. According to local witnesses, the speed of the fire was so high that burnt two young people on a scooter while they were trying to run out of the burning area. 26 people were burnt within a taverna that was located near the coastal part of Mati, while hundreds of citizens stayed into the sea for many hours. 1275 hectares were burnt in east Attica according to official measurements of the Copernicus emergency service while more than a thousand buildings were destroyed by the fire. The authorities, apart from East Attica had to deal a fire event that occurred in West Attica (region of Kineta, mountains of Geraneia) few hours before. The combination of those two fire events really struggled the antifire mechanism of the country.

This fire event, until today, is the country's deadliest since the start of modern Greece, and the world's second deadliest of the 21st century, after the Victorian fires.

DATA AND MATERIAL USED

The data were collected by using a crawler developed by Andrea Tarquini (https://github.com/h4t0n/). 15011 photographs, along with the corresponding timestamps and captions, were crawled. All of data contained at least one of the following hashtags: #athensfire, #prayforathens, #prayforgreece and #matifire. This amount of photographs is about the 38% of the total photos available in Instagram, containing those certain hashtags. The author chose not to use a certain bounding box as the news about this event were spread at a global level. The dataset consisted of 4 json datasets which included the timestamp information, the online url and the caption of each image. All images were downloaded by using a wget command in a Linux terminal.

Apart from the crawler, the author also used the Calc of LibreOffice software, for some basic edits on the dataset, R-studio for converting json files to csv and for creating scatterplots, and finally ArcGIS Pro software for creating the final maps.

METHODOLOGY

The methodology applied, was consisted on five basic steps (Figure I). The first step was related to crawling the appropriate volume of Instagram posts according to the most representative and descriptive to the fire event hashtags, while the second step was linked to the data preparation; the conversion of the files that contain the crawled information in an spreadsheet-friendly form along with the selection of the data posted within certain time periods. In the third step, the selected posts were classified into certain defined categories considering each photo and each photo's caption. In this initial investigation, 4 certain categories were defined: a. fire identification, b. disaster management info, c. consequence score values assessed from each image's caption and d. consequence score values assessed from each image. The consequence score values score board was presented in previous research (Arapostathis and Karatzia 2019) and is associated to indicating a certain numeric value that represents effectively the negative impact of each consequence as it is described in each post. The score range is defined from I to V; value I represents the simple fire event identification while value V is strictly associated to the human loss (table I). In cases of different consequence scores between the photo and the caption the highest value was selected as a default rule.

Table I: Description of the conceptual consequence score value range

CONSEQUENCE SCORE VALUES	DESCRIPTION
I	Simple fire event identification
II	Small areas consisted of burnt woodland
III	Emergency situation, large areas are burnt, property in danger
IV	Danger of human life, burnt property, extremely large areas are burnt
V	Human loss

The next step of the methodology was linked to geo-referencing. In this stage, the geo-referencing was performed by considering only the detection of geographic coordinates that exist within each photo's caption. The geo-referencing method applied, was presented in previous research for the social media network twitter (Arapostathis et al. 2018). In brief, the number of the geographic entities that are contained within the text of each caption was noted and each caption was replicated N times where N was the number of detected entities. Afterwards, the corresponding x, y coordinates were added for each caption in a way that each geographic entity of a group of replicated posts was represented once. Moreover, a geographic precision score value according to the precision level of each mentioned geolocation was indicated. Those score values range also from I to V, where I refers to the most precise geolocations (a POI, or a certain street name and number) and V is the most general, related to the administrative level of a prefecture/provincia (table II).

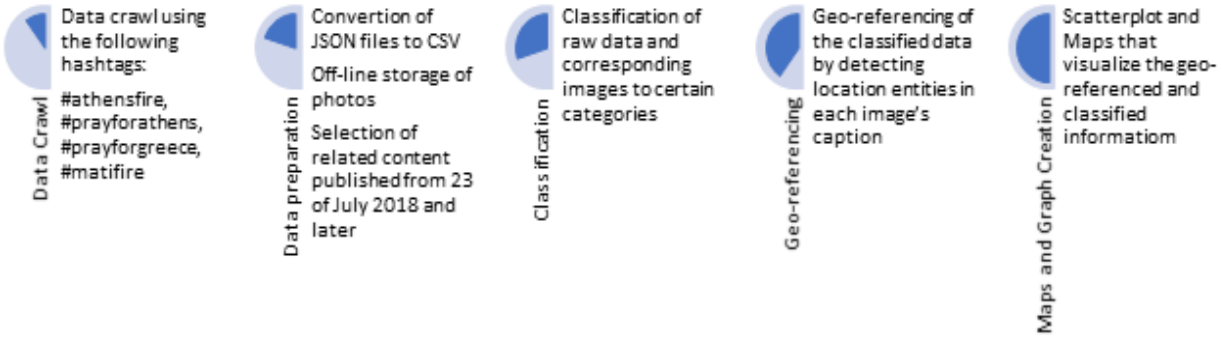
Table II: Description of the geographic precision score value range

GEOGRAPHIC PRECISION SCORE VALUES	DESCRIPTION
I	Street name and number or Specific POIS
II	Street name
III	Neighborhood or hamlet
IV	Municipality
V	Prefecture and above

Finally, the spatial distribution of all the pairs of x, y coordinates were randomized within the polygon that represents each detected geolocation. All the randomized coordinates were stored in a table which also contains the classified information. Even there is previous research related to the development of an R-script that automates

this geo-referencing technique (Arapostathis 2018) due to the initial stage of the analysis it was preferred to check a data sample, manually, checking each post in an 1 by 1 basis in order to gain experience and explore hidden potentials of Instagram, regarding the content of each post. The final step of the methodology was consisted on creating various maps and graphs that were suitable for an initial analysis of the data; In specific scatterplots were created that visualize the volume of information in certain time periods. The starting point of the time periods is the 23rd of July 2018, at 18:00 (Greek summer zone time). Moreover, three maps were generated containing information regarding a. the quantity of posts in each geographic area, b. the geo-referenced information regarding disaster management and c. the geo-referenced consequence score values, respectively. (Maps I, II, III). The total number of processed Instagram posts was 1070.

Figure *I: Methodology*



RESULTS

Figure II: Scatterplots of Instagram posts within certain time periods

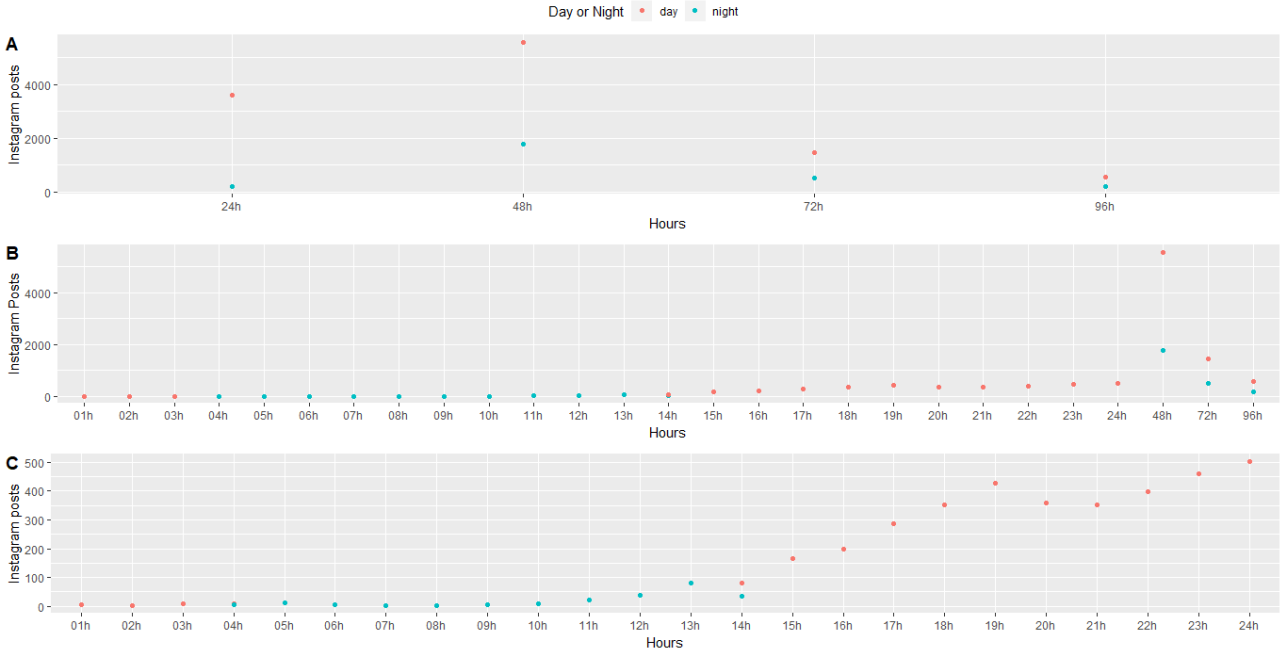
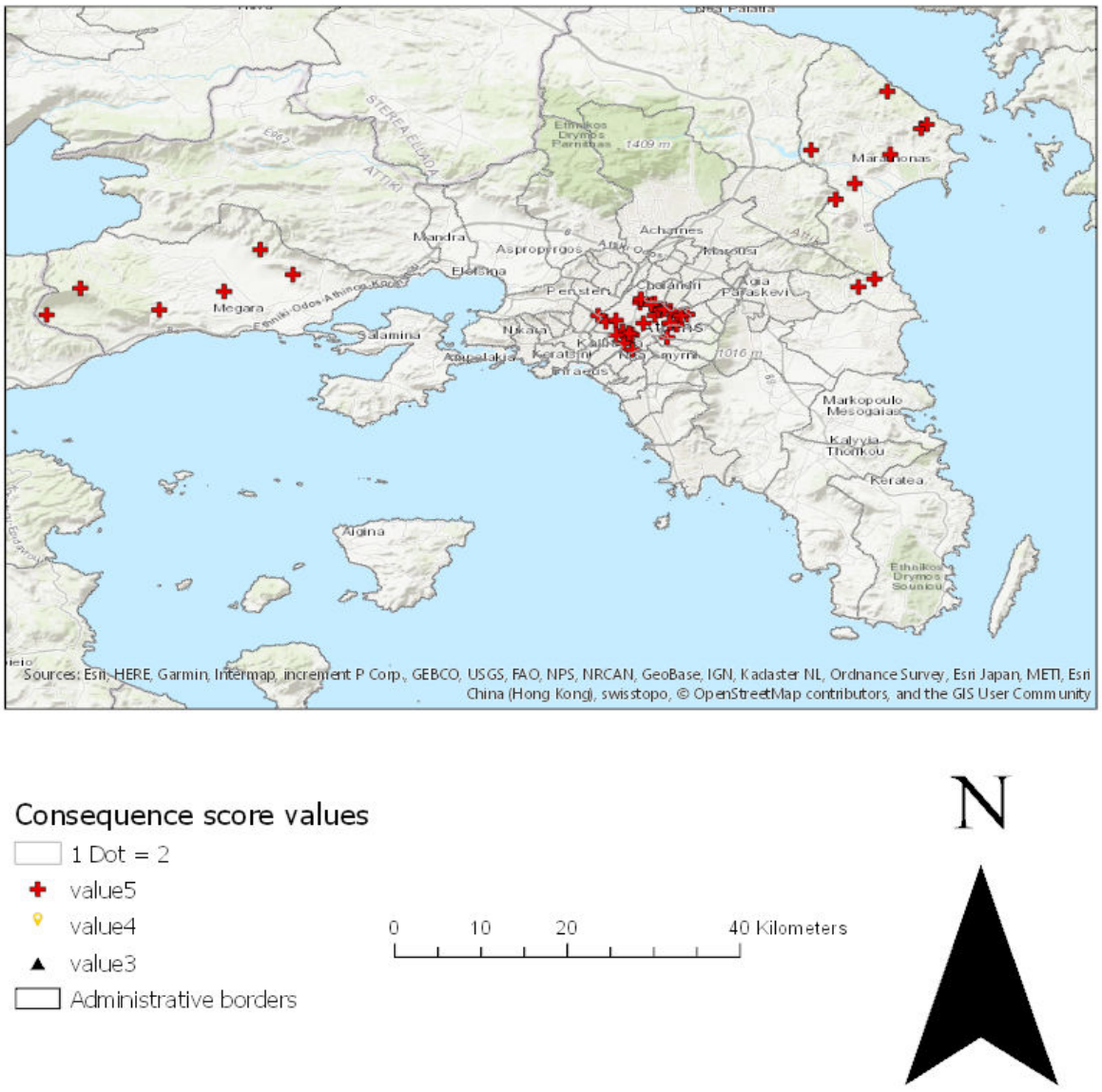


Figure II provides an interesting insight regarding the published quantity of Instagram posts through time. Axis X demonstrates the time periods values in hours (h); time starts since the occurrence of the fire event. In Axis Y the volume of instagram posts is displayed while the different colors represent the day-night condition. The most

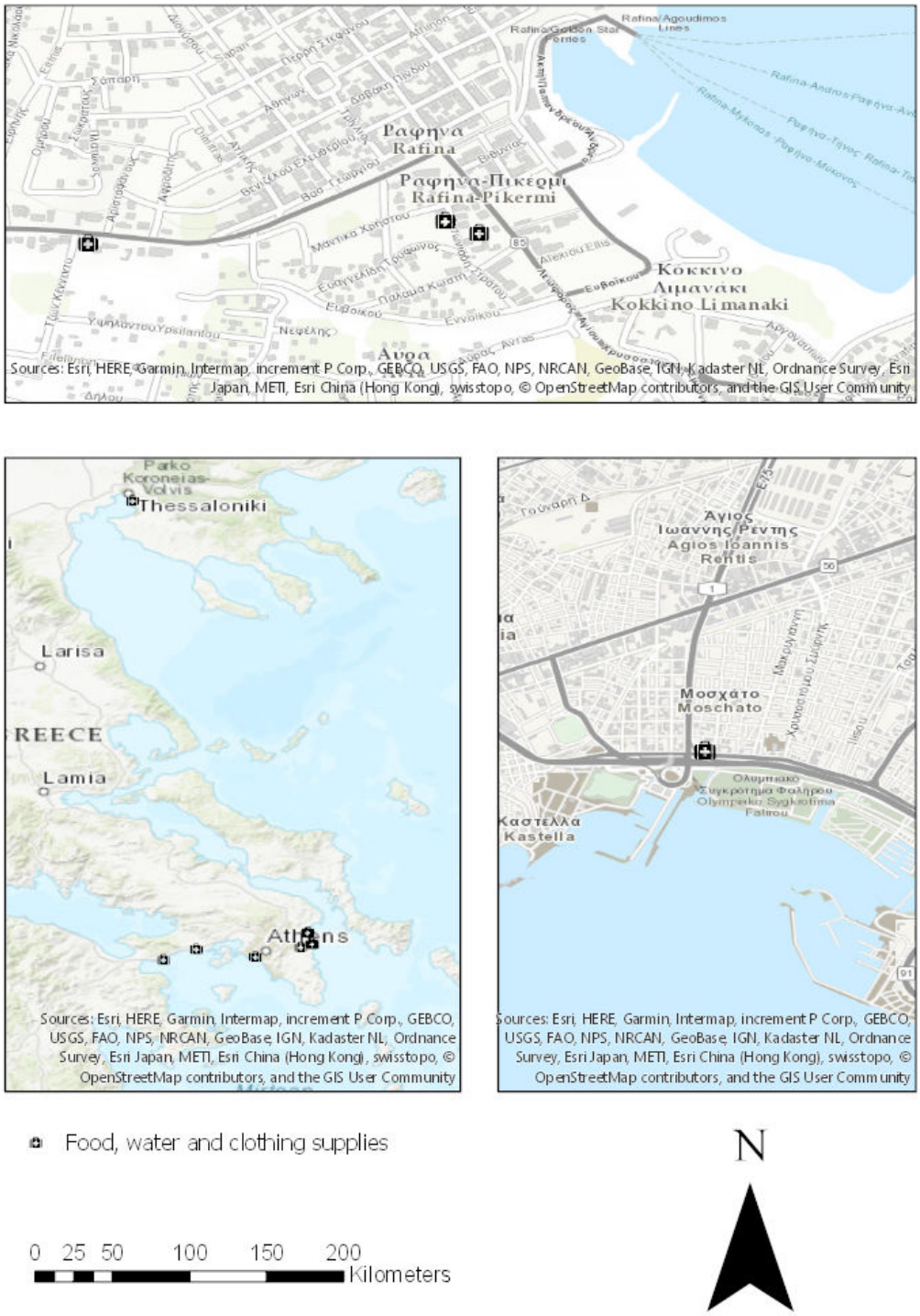
interesting part is that within the first hours, since the start of the fire event, the volume of related published posts is impressively low. The volume starts to grow significantly just after the first 13 hours while the total production is almost doubled after the first day.

Map I: Consequence Value Scores according to Instagram data (after analyzing 1100 posts)



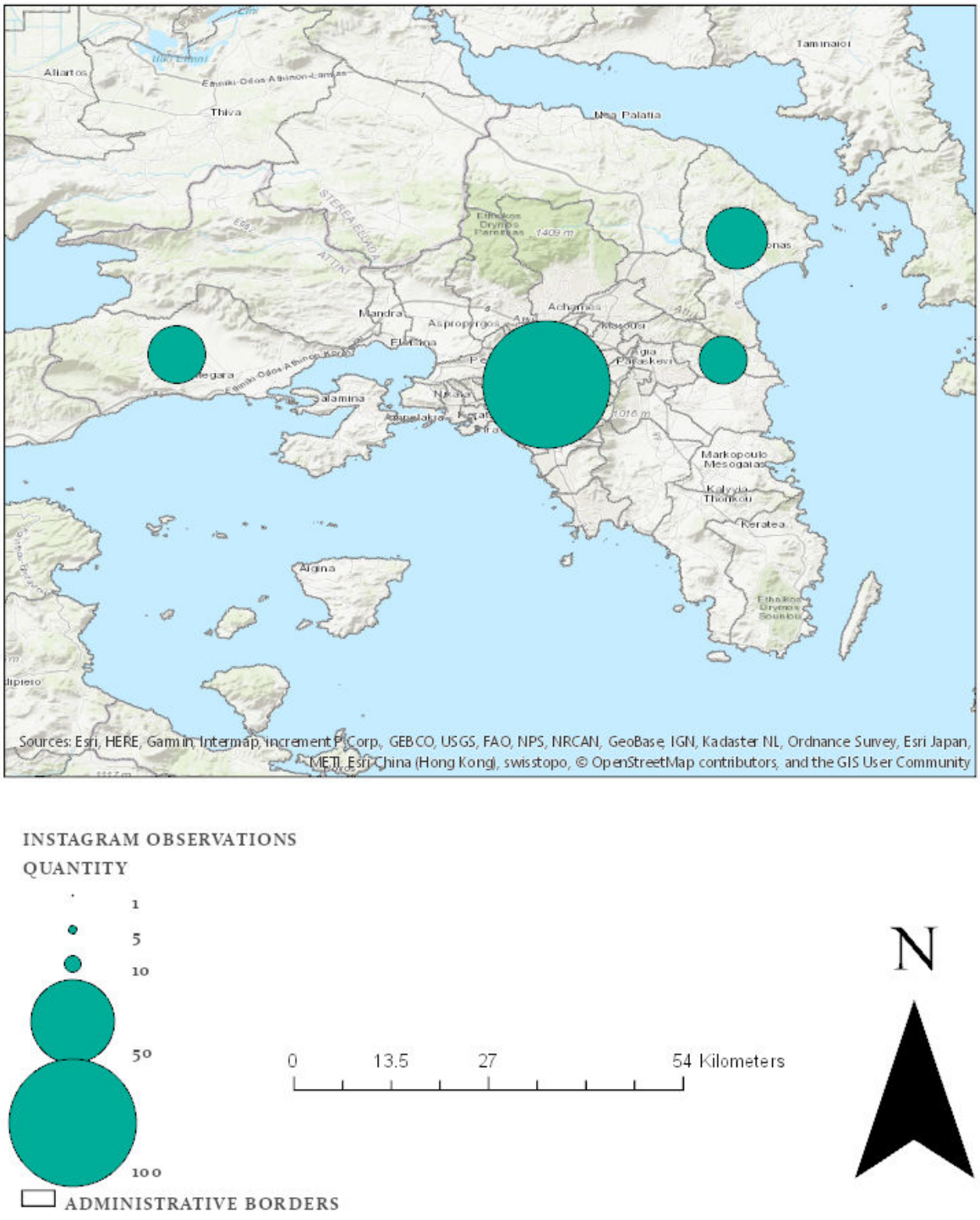
In Map I the geo-referenced consequence score values are vizualized. The outcome was a result of applying the methodology presented in previous sections. As already stated, value 5 (symbol of red cross) is linked to the human loss while each symbol represents two Instagram posts that indicate the same consequence score value. In reality, the human losses were located only at the east part of Attica. The crosses located in the municipality of Athens (central part of the map) appear due to the high values of the geographic precision that many posts received. A lot of people used the word Athens, while posting, in order to describe the whole region that is displayed in Map I (known as Tsipras syndrome). That region is the prefecture of Attica. The red crosses at the west appear due to a fire event that occurred in that area, few hours before the East Attica fire event. As a result, many Instagram posts included information for both fires along with the information that there are dead people, without clarifying the certain area in which the people died.

Map II: Disaster Management Maps: Locations for collecting resources for the fire event victims



Map II is more close to the desired final output of disaster management maps. Contains the most precise Instagram observations in terms of geography. Those spots that appear are at precision level I (POI, or street name and number) and visualize various places for collecting food and water supplies along with clothes or any other material that would be useful for the victims of the fire event.

Map III: Proportional map: Quantity of Posts in certain areas



In Map III the spatial distribution of the volume of geo-referenced posts is displayed. The map uses proportional symbols in order to visualize the quantities. The displayed symbols at the east are within the main affected areas from the fire event that was analyzed in current research, while the symbol at the west identifies a fire event that occurred in West Attica few hours before. Finally, the big circle in the center of the map is linked to the geographic precision issues (the so-called Tsipras syndrom) of the information as many Instagram posts disseminated the information that there is a fire event in the geographically general area of Athens.

DISCUSSION – CONCLUSIONS

Instagram is a powerful social media network that was surely not designed for disaster management purposes. However, major disaster events seem to concern Instagram users, who post at a high volume at least, in catastrophic events. One of the most interesting output of this research is the latency between the start of the fire event and the post of related information. This characteristic of Instagram is rather different to other social media networks, such as twitter, the dissemination of information through which, is performed almost instantly. This time lag makes Instagram rather not useful during the initial response phase of the disaster management procedures. The plethora of information though gives a nice insight regarding event-tracking purposes and for displaying some important information about disaster management procedures that are performed after the initial response. The appropriate geo-referencing of the information is still under development. Although some of the Instagram Posts may contain the x y coordinates of the spot that a photo is published, the credibility of that information is ambiguous as according to Huiji and Barbier (2011) and logical assumptions, a post could be published from another geographic place than the place that the post refers to. However, a more detailed analysis regarding that part, needs to be performed in the future in order to investigate all the potential aspects of the embedded geographic information. Moreover, the geo-referencing method used in this research extracts many coordinates. There seems to be a mess though when people are generalizing the areas in which they refer to.

One of the most important advantages of Instagram is the ability to publish a photo, as those are very helpful for classifying purposes. Although a photo has the power to instantly describe a whole situation, it is logically assumed that in disaster management situations not all photos are published. For instance, as Instagram is designed mostly for fun purposes, it is rather rare to find pictures of dead people, information that could be vital during DM procedures. That certain information though is published, in a high rhythm, within each photo's caption. Concluding, it seems that Instagram can act as a supplementary source, by giving very good insights in certain parts of the DM process. However, the final assumptions need further research.

The future steps of this introductory analysis include the processing of the total dataset, the application of SVM techniques for classifying images to the appropriate categories in almost real time, the development of more meaningful to the DM stakeholders and participants, graphs and maps. Finally, the automation of the whole steps of the methodology in a way that it could be executed at once and in real time is vital for the applicability in DM situations in live time.

REFERENCES

Arapostathis S. G. (2018), "Automated Methods for Effective Geo – Referencing of Tweets Related to Disaster Management", International Geomatics Appliations Conference – Book of abstracts (online), ISSN: 2653-9098, page 62.

Arapostathis, S. G., Karantzia, M. (2019). Mapping Information of Fire Events, from VGI Source (Twitter), for Effective Disaster Management (in Greece); The Fire of North-East Attica, August 2017 (Greece) Case Study. In Advances in Remote Sensing and Geo Informatics Applications (pp. 257-260). Springer, Cham.

Arapostathis, S. G., Lekkas, E., Kalabokidis, K., Xanthopoulos, G., Drakatos, G., Spirou, N., Kalogeras, I (2018).: Developing seismic intensity maps from twitter data; the case study of Lesvos, Greece 2017 earthquake: Assessments, improvements and enrichments on the methodology, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-3/W4, 59-66, https://doi.org/10.5194/isprs-archives-XLII-3-W4-59-2018, 2018.

Dashti S., Palen L., Heris M. P., Anderson K. M., Anderson S., Anderson T. J. (2013) Supporting disaster reconnaissance with social media data: a design-oriented case study of the 2013 Colorado Floods. In Proceedings of the 11th International ISCRAM Conference – University Park, Pennsylvania, USA .

Goodchild MF (2007) Citizens as sensors: the world of volunteered geography. Geojournal 69(4):211-221.

De Albuquerque, J. P., Herfort, B., Brenning, A., Zipf, A. (2015). A geographic approach for combining social media and authoritative data towards identifying useful information for disaster management. International Journal of Geographical Information Science, 29(4), 667-689.

De Brito M., Evers, M., Almoradie ADS (2018) Participatory flood vulnerability assessment: a multi-criteria approach. Published by Copernicus Publications on behalf of the European Geosciences Union.

Girres, J. F., Touya, G. (2010). Quality assessment of the French OpenStreetMap dataset. *Transactions in GIS*, *14*(4), 435-459.

Grunder-Fahrer S., Schlaf A., Wustmann S. (2018) How social media text analysis can inform disaster management GSCL 2017, LNAI 10713, pp. 199-207. https://doi.org/10.1007/978-3-319-73706-5_17

Haklay, M., Basiouka, S., Antoniou, V., Ather, A. (2010). How many volunteers does it take to map an area well? The validity of Linus' law to volunteered geographic information. *The Cartographic Journal*, *47*(4), 315-322.

Huiji, G., and Barbier, G. 2011. Harnessing the Crowdsourcing Power of Social Media for Disaster Relief. IEEE

Intelligent Systems 26 (3): 1541-672.

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., Meier, P. (2013, May). Extracting information nuggets from disaster-related messages in social media. In Iscram.

McDougall K. (2011) Using Volunteered Information to Map the Queensland Floods In: Proceedings of the Surveying Spatial Sciences Biennial Conference 2011. 21 – 25 of November 2011, Wellington, New Zealand .

Morstatter F., Pfeffer J., Liu H., Carley K. M. (2013). Is the sample good enough? Comparing data from twitter's streaming APIwith Twitter's firehose. In Proceedings of the 7th International Conference on Weblogs and Social Media, ICWSM 2013 (pp. 400-408). AAAI press.

Rahman M. M., BaruaU., Khatun F., Islam I., Rafiq R. (2018) Participatory vulnerability Reduction (PVR): an urban community-based approach for earthquake management. Natural Hazards. https://doi.org/10.1007/s11069-018-3364-2.

Smith L., Liang Q., James P., Lin W. (2017) Assessing the utility of social media as a data source for flood risk management using a real-time modelling framework. Journal of Flood Risk Management 10:370-380

Yin J., Lampert A., Cameron M., Robinson B., Power R. (2012) Using Social Media to Enhance Emergency Situation Awareness IEEE Computer Society pp 1541-1672.

Zhong, X., Duckham, M., Chong, D., Tolhurst, K. (2016). Real-time estimation of wildfire perimeters from curated crowdsourcing. Scientific reports, 6, 24206.

Track 7.

Planning, Foresight and Risk Analysis

Chairs

Murray Turoff, *New Jersey Institute of Technology, USA*

Victor A. Bañuls, *Pablo de Olavide University, Spain*

Challenges in Community Resilience Planning and Opportunities with Simulation Modeling

Abbas Ganji
University of Washington
ganjia@uw.edu

Negin Alimohammadi
University of Washington
ngn.alimohamadi@gmail.com

Scott Miles
University of Washington
milessb@uw.edu

ABSTRACT

The importance of community resilience has become increasingly recognized in emergency management and post-disaster community well-being. To this end, three seismic resilience planning initiatives have been conducted in the U.S. in the last decade to envision the current state of community resilience. Experts who participated in these initiatives confronted challenges that must be addressed for future planning initiatives.

We interviewed eighteen participants to learn about the community resilience planning process, its characteristics, and challenges. Conducting qualitative content analysis, we identify six main challenges to community resilience planning: complex network systems; interdependencies among built environment systems; inter-organizational collaboration; connections between the built environment and social systems; communications between built environment and social institutions' experts; and communication among decision-makers, social stakeholders, and community members. To overcome the identified challenges, we discuss the capability of human-centered simulation modeling as a combination of simulation modeling and human-centered design to facilitate community resilience planning.

Keywords

Community resilience, human-centered design, interface design, simulation modeling, recovery planning, mitigation planning, human-centered simulation modeling.

INTRODUCTION

Community disaster resilience is defined as "the ability of a community to prepare for anticipated hazard, adapt to changing conditions and withstand and recover rapidly from disruptions" (NIST 2016: V.1:1). Resilience of community is built upon a variety of community aspects that have been extensively investigated in research studies (Aldrich and Meyer 2015; Comes and de Walle 2014; Chang and Rose 2012). As disasters may cause extreme damage and long-lasting disruptions in community functioning, it is vital for community stakeholders to envision potential damages and expected recovery process beforehand. For this purpose, several community resilience planning initiatives have taken place in the U.S. in the last decade to identify community hazards, anticipate the recovery processes, establish community resilience goals and provide recommendations for decision-makers to achieve better community resilience (OSSPAC, 2013; WASSC, 2012; Poland, 2009).

Community resilience is complicated and multi-dimensional on its own. Community resilience planning, in practice, is a highly collaborative process that involves numerous community stakeholders associated with human-oriented challenges. Participants in community resilience planning include emergency managers, experts and managers of building and infrastructure systems, social stakeholders, and so on. Community resilience planning is technical and domain-oriented and requires a comprehensive understanding of the recovery process of damaged entities in the built environment and social systems. In addition to being a complex puzzle, community resilience planning is a highly user-centered process, requiring collaboration among built

environment experts with different areas of expertise, communication among experts of the built environment and social institutions, and information sharing among the planning participants, community stakeholders, governmental and elected officials, and community members. It is essential to recognize and understand the complexity of the planning process and its characteristics. As well, considering that several community resilience planning initiatives taken place in the U.S., it is beneficial to learn from these experiences to facilitate future initiatives.

In this study we investigate the process of community resilience planning and identify challenges that participants experienced in previous planning initiatives as our first research question. The next step is to determine how community resilience planning can be facilitated. Simulation modeling is widely used to model connectedness and interdependencies in network systems such as infrastructure systems (Ramachandran et al. 2015). Several research studies have successfully used simulation models to investigate community disaster recovery processes (Miles at al. 2018). However, no analytical computer-based tools like simulation models have been used in previous planning initiatives. As our second research question, we investigate if simulation models can facilitate planning initiatives, and if so, how they can address the identified challenges. Analyzing interviews conducted with experts who participated in the initiatives, we conclude that combining human-centered design with simulation modeling, referred as human-centered simulation modeling, has the potential to address observed challenges.

BACKGROUND

Community resilience is a community attribute that can be improved and adapted over time; it refers to the ability of a community to mitigate and resist against hazards and its ability to recover quickly (Bruneau et al. 2003). Several frameworks have been developed to describe the foundations of community resilience in different domains (Miles 2015; Kuling et al. 2013; Norris et al. 2008). As disasters impact various aspects of a community, community disaster resilience is also considered in diverse dimensions such as social institutions (Aldrich and Meyer 2015; Alipour et al. 2015; Semaan and Hemsley 2015), physical infrastructure (Cimellaro et al. 2011; Davis et al. 2018), economics and business (Chang and Rose 2012), and healthcare (Chandra et al. 2011; Comes and de Walle 2014). Berkes and Rose studied the characteristics of community resilience and integrated two dimensions of social–ecological systems, the psychology of development and mental health, in a framework (Berkes and Rose 2013). Chang et al. developed an approach to characterize communities' infrastructure resilience and identified key challenges including incomplete incentives and partial information (Chang et al. 2014). Berk et al. analyzed coastal state hazard mitigation plans and compared the quality of these plans (Berk et al. 2012). Labaka et al. (2014) presented a framework to identify resilience policies across technical, organizational, economic, and social dimensions (Labaka et al. 2014). Rubim and Borges (2017) conceptualized and characterized resilience in the context of complex systems (Rubim and Borges 2017). Turoff et al. developed a model for interaction among critical infrastructure systems (Turoff et al. 2016). Additionally, many research efforts have attempted to quantify community resilience and identify quantitative indicators and indices to evaluate different dimensions of community resilience (Cutter et al. 2016 and 2010; Bruneau et al. 2003).

Community resilience planning requires community decision-makers, built environment experts, and social stakeholders to collaborate to identify social goals and their dependencies (NIST 2016: V.1:1). This broad collaboration and communication among experts in different systems and non-experts makes community resilience planning more challenging due to involving human-factors in the planning process. Characteristics and challenges in emergency management have been extensively studied (Scholl and Carnes 2017; van Laere et al. 2017; Turoff et al. 2016; Gonzalez et al. 2012; Maitland et al. 2009; Dilmaghani et al. 2006). However, the existing literature does not specifically identify challenges in community resilience planning. In next section, we introduce three community seismic resilience planning taken place in the US in last decade. The initiatives are a valuable source for finding existing barriers in community resilience planning.

COMMUNITY SEISMIC RESILIENCE PLANNING IN THE U.S.

Bruneau et al. (2003) published one of the early research studies to define the concept of community seismic resilience (Bruneau et al. 2003). They defined community seismic resilience as "the ability of social units (e.g., organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes" (Bruneau et al. 2003). They also proposed a framework to quantify community resilience to be evaluable and measurable. This research and other studies led community experts to apply and quantify community resilience to real communities. Recognizing the importance of community resilience in the research studies, seismic

committees and urban planning associations formed and organized planning initiatives to assess resilience of their own communities.

SPUR Resilient City (2006-2009)

The first attempt at community seismic resilience planning was organized by the San Francisco Bay Area Planning and Urban Research Association (SPUR) (Poland, 2009). Experts from architecture, engineering, urban planning, and public policy planning firms were invited to work together to envision what would happen to the city after a high-magnitude earthquake. In this initiative, participants defined the concept of disaster resilience, selected a single city-wise expected earthquake scenario (10% occurrence in 50 years) as the community hazard level, established desired timeframes of recovery for buildings and infrastructure systems, estimated the anticipated resilience state for identified clusters of buildings and infrastructure systems, and provided recommendations for elected officials and community stakeholders. Comparing anticipated and desired resilience states identifies the gap between where the community is and where it should be. This concept has become more popular in similar studies. It should be noted that the current (anticipated) recovery timeframes were collaboratively estimated based on experts' judgment. This work inspired seismic committees in other states, and the procedure was followed by other community seismic resilience planning initiatives with some modifications.

Resilient Washington State (2010-2012)

In 2010, the Resilient Washington State (RWS) subcommittee of the Seismic Safety Committee under the Washington State Emergency Management Council launched a community seismic planning initiative for the state of Washington inspired by SPUR (WASSC, 2012). Since RWS held a statewide initiative, they referred to National Seismic Hazard Maps created by the U.S. Geological Survey (USGS) in 2008 to identify community hazard. RWS formed four groups consisting of critical services, utilities, transportation, and housing & economic development sectors, identified their components, and located experts from these sectors. They followed the SPUR procedure, identified community hazard, and presented desired and anticipated recovery timeframes for community entities. They also provided several recommendations for community policy makers and published their report in 2012.

Oregon Resilience Plan (2011-2013)

The Oregon Resilience Plan (ORP) was conducted as a community seismic resilience planning initiative in 2011-2013 by the Oregon Seismic Safety Policy Advisory Commission (OSSPAC) (OSSPAC, 2013). They considered a M9.0 Cascadia earthquake and tsunami as the community hazard for the state of Oregon. ORP consisted of eight task groups: Cascadia Earthquake Scenario, Business and Workforce Continuity, Coastal Communities, Critical and Essential Buildings, Transportation, Energy, Information and Communications, and Water and Wastewater. The planning process was similar to that of SPUR and RWS, but more detailed and specific to the state of Oregon. Compared to the previous initiatives, ORP perspicuously appointed long-term community goals and social needs. They established desired recovery timeframes of community entities such that business continuity in the state would not be disrupted for more than two weeks to one month. The task groups considered this goal as a criterion to identify desired recovery timeframes. As a result, the existing gaps between the anticipated state and desired state were well understood by community decision-makers and the initiative's audiences.

Community Resilience Planning Guide for Buildings and Infrastructure Systems by NIST (2016)

The National Institute of Standards and Technology (NIST) published a two-volume report, *Community Resilience Planning Guide for Buildings and Infrastructure Systems,* in 2016 examining these initiatives (NIST, 2016). This report brought community resilience planning to the forefront, with significant updates and details. Although NIST's report offered similar reasoning and conclusions as the initiatives themselves, it also provided valuable details on **how to proceed** with systematic community resilience planning. The NIST report identified community representatives who should be involved in planning. It also divided communities into the built environment dimension, including buildings and infrastructure systems, and the social dimension consisting of social institutions such as businesses, industries, and financial systems, and recommended identifying the characteristics of each dimension. More importantly, NIST suggested linking social functions with the built environment, a concept that was not explored in the existing initiatives. In this way, the relationships among numerous systems, in either the social or built environment, are well defined and the community is envisioned as it really is—an integrated whole rather than separate groups that function individually and independently. The

NIST report highlighted dependencies and cascading effects, and presented a dependency matrix among infrastructure systems, which had not been explored by the three initiatives although they had noted its significant impact.

Community resilience planning has evolved based on the lessons learned from the planning initiatives, actual events, and research studies. Similarly, the process of resilience planning has been enriched by taking into account more influential concepts, parameters and dimensions, and defining relationships among them. In summary, NIST suggested following the steps presented in Figure 1.

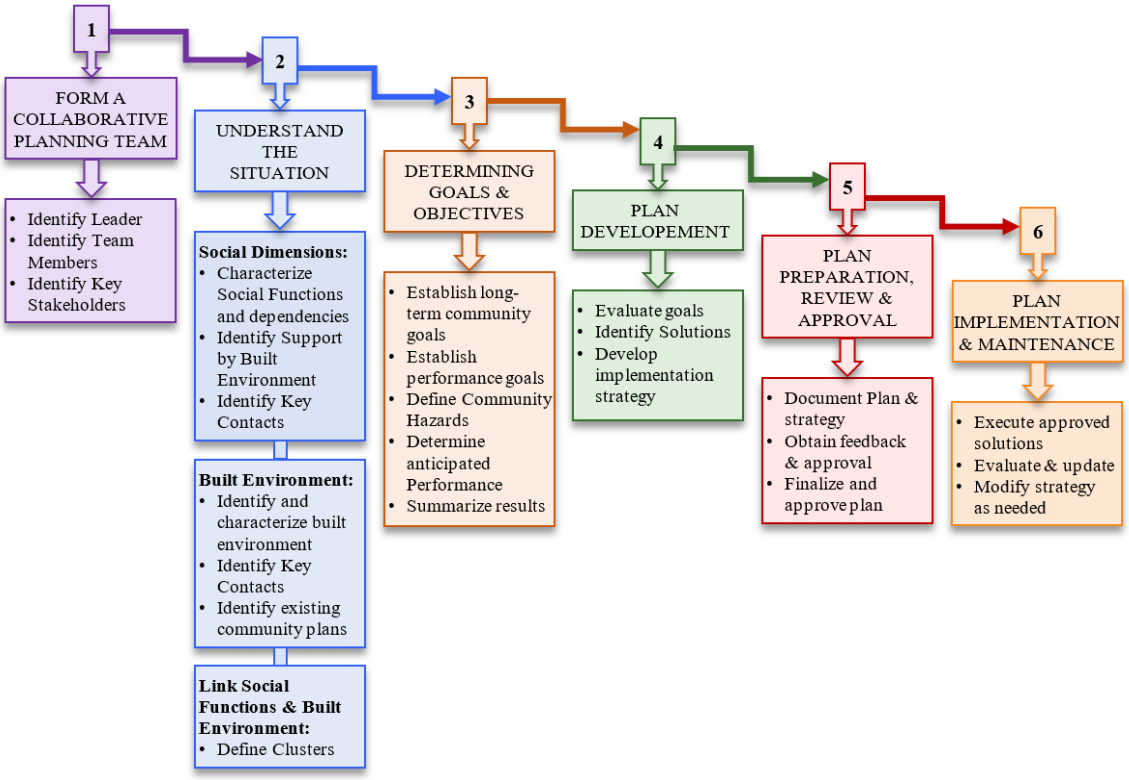


Figure 1. Six-step planning process for community resilience (NIST, 2016)

Although community resilience planning has grown quickly and NIST's report presented it as a standard and unified procedure, undertaking planning in practice comes with wide variety of surprises and challenges. In this study, we look for challenges that participants in the community resilience planning initiatives experienced. We also discuss possible ways to overcome these challenges.

METHODOLOGY

As mentioned earlier, we examine two research questions in this study. First, we aim to identify challenges appeared in the community resilience planning initiatives, and second, we want to investigate how simulation modeling can help this process from the participants' perspective. For this purpose, we reviewed the procedures and conclusions of three initiatives and conducted semi-structured interviews with the initiatives' participants to learn about the process and observed challenges. Details on the interviewees, data collection, data coding and analysis approach are provided below.

Participants and Data Collection

The first author of this study contacted several critical infrastructure agents, emergency managers, and researchers who participated in one of the initiatives via email, described the purpose of the interview, and requested a 90-minute in-person meeting to learn about their experience in the initiatives. He invited interviewees from different initiatives to recognize similarities and differences. He also interviewed a manager of critical infrastructure system who did not participate in any of the initiatives but has conducted several relevant research studies and community resilience discussion meetings with experts in infrastructure systems.

This interview was to include the perspective of an independent expert who did not participate in any of the initiatives. Overall, the first author conducted 90-minute semi-structured interviews with eighteen emergency managers, infrastructure and building experts, and researchers. Seventeen interviews were conducted in-person, and one interview was over the phone. Geographically, the interviewees were from California, Oregon, and Washington (five, seven, and six interviewees from each state, respectively). All interviews were recorded and transcribed with interviewee's permissions for further analysis except one interview where the interviewee did not grant permission to record the conversation. We relied on hand-written notes for that interview and included these notes in our qualitative content analysis. Interviews were voluntary and unpaid, and the interviewees were kind and welcoming. Interviews were conducted from May to September 2018.

Data Analysis and Qualitative Coding

Our data analysis was driven by open-coding thematic analysis. The first author applied line-by-line coding to five random interviews before establishing a codebook. Initial codes emerged from finding relationships based on the line-by-line coding. The third author, who is an experienced social scientist, university researcher, and expert in community resilience, inspected the initial codes. By establishing the initial codebook, the first and second authors coded the entire dataset. For collaborative qualitative coding, we used Code Wizard as a collaborative coding tool (Ganji et al. 2018). Code Wizard consists of programmed Microsoft Excel spreadsheets. Code Wizard is free, appropriate for small to midsize teams and academic research projects, and does not require much training, which was a significant concern for the authors. The first and second authors coded data independently and separately. Using Code Wizard, after each round of individual coding, we aggregated coded data, evaluated the Inter-Coder Reliability (ICR) coefficient, noted problematic codes, discussed the reasons for disagreement, and revised the codebook. We performed three rounds of coding to meet an acceptable ICR threshold (0.8). We coded data for two themes: (1) challenges and (2) opportunities for simulation modeling.

CHALLENGES IN COMMUNITY RESILIENCE PLANNING

Based on our qualitative content analysis, we present the main challenges in community resilience planning identified by the interviewees. We used the term **main** challenges because there were additional challenges mentioned in the interviews that we intentionally ignored. For example, a few issues occurred only in one of the initiatives and were not generalizable for other initiatives, and some other barriers taken place due to the logistics of holding meetings and time limitations.

Complex Network Systems

According to NIST, built environments that support community members and social community functions consist of infrastructure systems and buildings. Recovery of an infrastructure system to be able to provide services to consumers, regardless of its interdependencies with other systems, depends on two factors: (1) recovery of discrete damaged entities, and (2) the connections and dependencies among networked entities. Both factors should be considered in planning since ignoring either one results in a distorted and incomplete picture of the recovery process of infrastructure systems.

In the planning initiatives, participants formed task groups for infrastructure systems, and participated experts joined the groups based on their areas of expertise. Experts identified the main entities of each sector in the task group. Through technical discussions and aggregating experts' judgment, the task groups created anticipated and desired recovery timeframes for identified entities (see Figure 2). Experts typically estimated damages and recovery timeframes based on community hazard intensity, liquefaction and landslide potentials, and type, material, and age of entities.

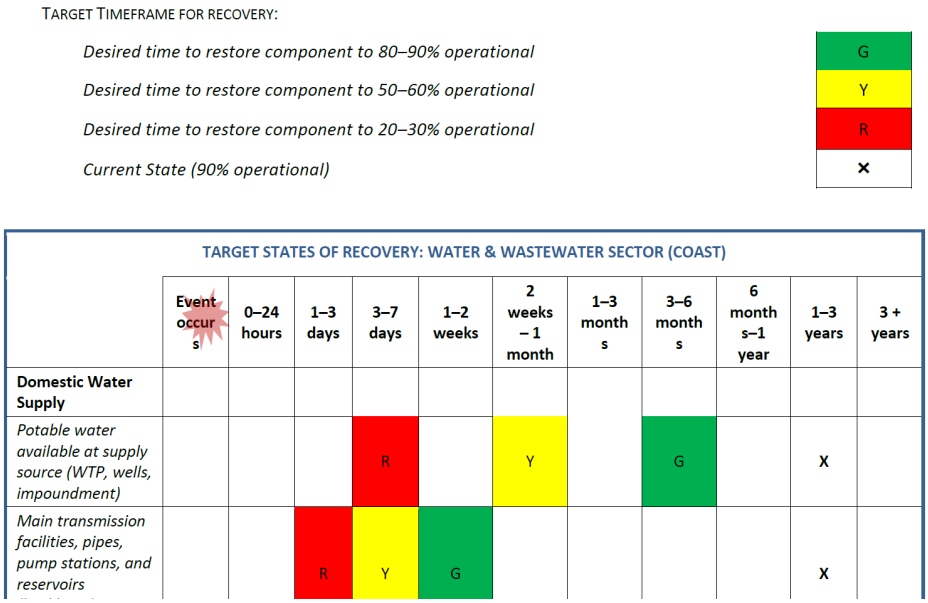


Figure 2. Desired and Anticipated Recovery Timeframe in Water & Wastewater Sector (OSSPAC, 2013)

Experienced experts provided insightful information to estimate required time for recovery of single entities. This information can be used as a basis in community resilience planning. However, overlooking the network and interconnected structure of infrastructure systems underestimates recovery timeframes from the perspective of community members who need these services regardless of the recovery of single entities. System resilience depends on the level of redundancy that exists in the system. This redundancy is gained from the network system and its structure, not just entities.

> *[Interviewee #7:] "…in water systems, there's so much dependency that exists, you've got to restore this before you restore that, before you restore that, and similarly in capacity… if you're going to restore the distribution system, you have to have sufficient supply to be able to meet that, but there's no need to build the supply capacity any faster than you can build the delivery system to be able to meet those needs."*

Due to lack of appropriate tools, and limited time and budget, the network and dependencies in infrastructure systems were not considered in the planning initiatives. In order to make anticipated recovery timeframe estimates more realistic, the network system should be taken into account in future studies.

Interdependent Network Systems and the Cascade Effect

A damage in an infrastructure system may result in disruption of serviceability of many other systems. This phenomenon, referred to **cascade effect,** is also observed in the recovery process of interdependent systems. For example, the water system relies on electricity for running pump stations and back-up generators. Therefore, serviceability of the water system depends on not only the functionality of the water system itself, but on the power system as well. Similarly, recovery of both water and power systems is contingent on access to damaged entities, which makes recovery process of water and power systems dependent on recovery of transportation system. The significant impact of interdependencies among infrastructure systems and buildings was noted in the planning initiative reports and discussed in more detail in the NIST report. However, interdependencies have not been taken into account for estimating anticipated recovery timeframes of built environment in the planning initiatives.

> *[interviewee #10:] "there are significant interdependencies. It's hard to really comprehend to what level they are important. To me, power is the big one. What can happen until power is restored? Not a whole lot...you probably can have some restorative construction happen without power, but even that's a challenge. Everything relies upon power, and how resilient is the power. What are those interdependencies, does that back everything else up in recovery?"*

Inter-Organizational Collaboration

In addition to the domain-oriented characteristics presented above, community resilience planning is challenging due to its inter-organizational nature. For example, infrastructure systems and buildings are managed by

different agencies, companies, and organizations with dissimilar procedures, priorities, and goals. Even a single infrastructure sector might be managed by multiple companies and decision-makers. Planning to make a community resilient entails all decision-makers from different organizations coming to agreement on how to proceed and what goals to pursue. Time needed for a community to recover after a disaster depends on the efficiency of experts' collaboration. For example, achieving desired recovery timeframes requires experts and managers in companies that are part of the power system (if there are multiple companies providing electric service for the community) to know how to plan for resilience to achieve these goals and how different policies might affect resilience of the entire community. Therefore, inefficient and ineffective inter-organizational collaboration is a big challenge in community resilience planning.

> *[Interviewee #2:] "In the power system, for example, there are multiple power system providers and they each have their own proprietary information, and probably many of them have done studies. [A company in infrastructure system] has studied some of their things, [another company in infrastructure system] has probably studied some of theirs, maybe they haven't studied everything, but a real challenge is getting access to that information, for starters."*

Similarly, interviewee #4 explains other challenges that emerge when decision-makers and stakeholders are from the public and private sectors and comply with different regulations:

> *[Interviewee #4:] "[infrastructure] is public and private, that's the important thing. Almost none of it is purely public, and so [...] there is proprietary information that those private sector companies hold close and have a right to hold close. And so, there are regulatory agencies, there's the utility and transportation commission, and they will honor their right to proprietary information. They try to work out planning with them, but some of it, for instance, even though you might say you want the hospital to come back first, [...] depending on the way the power outage happened, it may be that you have to fix something somewhere remote to there, because you also have to figure out how to bring the system back, and just bringing back one small branch of the system, even if it does feed the most vulnerable sector, may not do you the most good if bringing back a major substation gets you the most bang for your buck in the first twelve hours. And how they make that decision, again, is private."*

Connections between Social Institutions and Built Environment

Citizens and community members found social institutions to address their needs. NIST categorized social institutions in eight groups: (1) family/kinship; (2) the economy; (3) government; (4) health; (5) education; (6) community service organizations; (7) religious, cultural, and other organizations that support belief systems; and (8) the media. While the goal of community resilience is closely tied with the recovery of social institutions, these institutions themselves rely on functionality of the built environment (including infrastructure systems and buildings). Consequently, desired recovery timeframes for the built environment are established based on social needs. Social and built environments are connected in community resilience planning and it entails identifying "links between social functions to the supporting built environment" (NIST 2016: V.1:8). The importance of identifying these links has been gradually recognized in the community resilience planning initiatives.

The NIST report devotes an entire chapter to identifying these links. However, the three initiatives, while recognizing the importance of identifying these links, did not really consider these links to estimate anticipated or desired recovery timeframes. NIST and the planning initiatives present desired and anticipated recovery timeframes for the built environment by percentages of functionality of systems entities. For instance, the desired recovery time for functionality of 80-90% of distribution pipes is determined 1-3 days in Washington state (WASSC, 2012). The desired time to restore 50-60% of electric transmission lines in the "non-tsunami coast zone" in Oregon was determined 1-3 weeks (OSSPAC, 2013). However, it is not clear how these timelines have been assigned to support social institutions and community members where connections between the built environment and the social dimension are lacking. As another example, the ORP defines the desired recovery timeframes of infrastructure systems such that businesses, as a social entity, would not experience disruption in having infrastructure services longer than two weeks. Imagine a hypothetical scenario in which 60% of electric transmission lines have been recovered in two weeks (determined as desired recovery timeframe in ORP), but business institutions are relied on the 40% unrecovered systems. In other words, although the desired recovery timelines for the built environment may be met, it is not certain whether or not businesses would receive services from the built environment in two weeks.

> *[Interviewee #6:] "I think the other biggest shortcoming was there wasn't the opportunity to go through and say, "here is an integrated set of recommendations drawn from each of the areas that together get us the furthest down the line to resilience and … address the question of what's the appropriate sequencing and balancing of these things."*

It should be noted that connection and dependence between the social dimension and built environment is mutual. While we described how recovery of the social dimension depends on the built environment, recovery of the built environment also relies on social dimensions. For example, recovery of infrastructure systems or buildings is executed by experts, crews, engineers, and infrastructure managers. As community members, they need social institutions such as healthcare and finance/economic institutions to be able to first survive and then participate in the recovery process.

> *[Interviewee #7:] "… their experience [New Orleans Water and Sewer Board] was so revealing to me. When [Hurricane Katrina] happened, they had all of this flooding, they had all of these facilities out. More than half of their workforce did not come back to work, and so how can you restore the system and establish service to the community if you don't have the workforce necessary to be able to do anything more than basically keep the lights on? […] I can't just take just anybody and put them on a backhoe and tell them how to repair a pipe. I need trained people who are able to respond to this event and aid in the restoration and recovery of our water system. […] The other thing I want to leave you with is it goes way beyond just infrastructure. I touch on obviously the people part of it, and that's key, but the business operations side of what we do is equally important, and again, water is a wonderful example as a utility, but it's true with most every other lifeline with the exception of maybe transportation. Somebody has to pay the bill. And so, if we're out of business, we're not sending out bills, we're not collecting revenue, we're not paying out bills, and pretty soon… the good news is I can restore the water system, but I can't pay for the fuel because nobody will take my credit card. I can't pay the electric bill to run the pumps that I need, and so I don't have the ability to run a business, to be able to sustain this organization, to cut paychecks to the people that I need so desperately to be able to repair the pipes."*

Communication and Information Sharing between Experts in Built Environment and Social Institutions

Built environment experts such as managers, agents and decision-makers in infrastructure systems and social stakeholders involved in the planning must work together closely. As mentioned earlier, NIST states that decision-making for recovery planning is based on social needs and community goals. Since social dimension like social institutions depend on the built environment to be functioning, experts on the both sides must communicate to share required information. In addition to identifying physical connections and dependencies between these dimensions, collaboration and communication between stakeholders in these two groups are challenging for community resilience planning.

> *[Interviewee #13:] "So, as we move into thinking about resilience, which is about more than the structure, it's about the occupancy, it's about more than one building, it's about the organization like a community. We have to be open to working with other groups, and this is a challenge, because those other groups never heard from us, in fact they're much bigger than us. They don't want to really hear engineers, and they have almost no patience."*

One important aspect of this collaboration and communication is prioritization, which is challenging step in community resilience planning. Prioritization is inevitable due to time and resource limitations, and potential conflicts in community recovery. Communities have similarities but are completely different in terms of their built environment structures and social needs and cultural differences. Therefore, as NIST concludes, there is no global priority list or gold standard for decision-making in community recovery planning, and priorities should be determined in a community-to-community basis. It underlines the significance of needs to strengthen collaboration, communication and information sharing among decision-makers from any dimension.

> *[Interviewee #7:] "... there are competing needs for limited resources. How as a community do we prioritize those limited resources to be able to meet the needs of the recovery, to be able to get recovery balanced and do it in a way that limits loss of life and expedites the overall recovery process? This is so challenging."*

Information Sharing and Communication between Experts and Community Members

This category of challenges in community resilience planning came as a surprise in our interviews. The final audience of community resilience planning initiatives is members of the community and their elected officials. Executing the decisions made in community resilience planning is a very costly and lengthy process that requires the support of the community. Experts in community planning share information with community decision-makers, elected officials, community policy makers, and finally community members. They aim to inform community members and decision-makers about the hazards that threaten their community and warn them about potential consequences of such disasters. They also envision the community's preparedness to resist

and bounce back after the expected disaster and point out the gaps between the current and desired states of preparedness. Making a community resilient requires a budget and resources which are usually obtained from taxpayers. Resilience planning cannot successfully proceed if community members do not properly understand its importance and support long-term investments in it.

> *[Interviewee #10:] "So, [this is] all state taxpayers' money going in to support this grant program to get this money out. Some of the successes and challenges associated with getting the grant program up and running, included people who didn't understand why it was important to have safe schools... schools' job [is to] educate, not to do seismic mitigation of schools. So, there was a really big learning curve for [...] really a lot of people."*

Considering the notes above, communication with the wider community is challenging because it has its own complexities and requires specific types of skills, especially when people have incorrect perceptions about the likely post-disaster condition.

> *[Interviewee #6:] "I think it was not well understood on the part of the public... [T]hat was one of the most important things that the resilience plan did was really put some parameters on it that the public could access, and I think that a lot of the public perception in the past had either been "oh, it's not going to be that big of a deal, I don't need to worry about it" or "it's going to be the end of the world, so why should I worry about it, there's nothing I can do, everything is going to be completely destroyed." Some of the commentary that came out from Tohoku, and some of perceptions that people got from the New Yorker article kind of fueled that notion of "oh my god, it's going to be this total disaster and nobody's going to survive, there's no point in preparing." And the resilience plan, I thought, the clearest message of it was "pretty much everybody is going to survive, and you're going to get up the next morning and not going to be able to flush the toilet for three months. That's going to be your problem." That's what we have to address, is that massive disruption to everyday life that is going to make it very difficult to live here, and certainly going to make it very difficult to continue to be employed here. And so … although at the time I felt like we're just doing this, engineers are just kind of guessing in terms of the damage and they tend to guess conservative when put in those kinds of situations, I think it still ended up with the right overall message which is "this is going to be really difficult, but there are things you can do to solve, to fix it, and move ahead with it."*

FACILITATING COMMUNITY RESILIENCE PLANNING BY SIMULATION MODELS

Reviewing the reports published after the planning initiatives and based on the interviews, we noticed that other than Hazus, which was used limitedly for damage and loss estimations, no analytical computer-based tools have been used in any planning initiatives. For example, estimating anticipated recovery timeframes of damaged community entities are computationally challenging tasks in the planning initiatives. However, use of analytical computer-based tools such as simulation models was lacking in the planning process.

Simulation models are nowadays used in numerous fields such as engineering, urban planning, and supply chain management. The capability of simulation modeling to improve different phases of emergency management is widely recognized in research communities like Information Systems for Crisis Response and Management (ISCRAM). Similarly, in practice, Federal Emergency Management Agency (FEMA) emphasizes the importance of tools in emergency management, noting that "innovative models and tools" are one of three strategic needs to accomplish recovery planning (FEMA, 2012). Simulation modeling is also used in community resilience. The interviewees were asked about how simulation modeling could help them in community resilience planning. It should be noted that most of the interviewees had experience or knowledge about simulation modeling and its capability in community resilience planning. For other interviewees who had no experience, background or information in using simulation models in this field, we shortly explained how simulation modeling works and provided some examples from the literature. We analyzed their answers and categorized their responses based on the codebook that we had established to identify the challenges since (1) we could maintain the consistency of presented concepts for our audiences, and (2) we could benefit from the details provided by interviewees to understand what tasks and functionalities are needed to handle by simulation modeling in this process. The interviewees' responses reveal what limitations and challenges can be addressed by simulation modeling and where simulation models can facilitate them. In the following, we present the benefit of using simulation modeling to address each category of identified challenge.

Complex Network Systems

As discussed previously, infrastructure systems are complex networks. In such complex systems, it is extremely difficult to predict how recovery proceeds and when these systems would be able to provide services to others,

including community members, social institutions, and other dependent infrastructure systems. Simulation modeling has the capability to consider this complexity, and many research studies have used simulation modeling to simulate the post-disaster recovery process of infrastructure systems and housing as mentioned in background section. The interviewees also mentioned that simulation modeling would be helpful in community resilience planning.

> *[Interviewee #5:] "I believe if there were modeling tools available to estimate downtime, the connectedness, and the dependencies of the different lifeline sectors, … and how doing certain fixes would improve the rapidity of getting things up and running quickly, I think it would help with building resilience and mitigation projects."*

Simulation modeling also makes planning much easier if experts would like to update data. If a simulation model is already set, new updates in system entities taken place over time can be simply applied to the model to adjust outputs accordingly.

> *[Interviewee #8] "And a tool would be nice to have, something where [... it] allows you to improve the data. So, you can put in with what you know, understanding your margin is bigger, but as you get better data, that comes around [...] that can be updated and give you better results."*

> *[Interviewee #12] "we need to figure out the things that we can't work around after the disaster ... that's what the days, weeks and months are about, to identify how much time they can have to get something going again but do that kind of simulation so that you can understand what you can work around."*

Interdependencies Among Infrastructure Systems

The advantage of using simulation models to capture the complexity of system interdependencies in community resilience planning was mentioned by the interviewees more than other simulation modeling capabilities. Simulation modeling has been widely used to simulate interdependencies among critical infrastructure systems in urban planning.

> *[Interviewee #7:] "simulation modeling would really be critical to illustrate this interdependency effect … and again, I had not noodled through it, everything, when I give this talk at many different seminars, I talk about interdependencies and how everything is connected to everything."*

> *[Interviewee #14:] "If there was a way to facilitate the collaboration over the issue of interdependence, right, if there was a way to synthesize the data that reflects the way one system depends on another, and then use that to run scenarios."*

> *[Interviewee #2:] "I think, what you're talking about [possibility of using simulation modeling], in terms of being able to model those interdependencies, [is] very valuable, and then being able to communicate that, again, to the community, to our power providers, and having redundant systems, redundant load paths to bring power into the community, that's the ultimate goal."*

Inter-Organizational Collaboration

Planning for community resilience is highly collaborative. Experts need to collaborate with each other since organizations have their own plans, policies, and priorities, but their decisions impact other groups' planning. This collaboration is difficult to facilitate when several organizations are involved; this is another area where simulation modeling can be used, as it can facilitate information sharing among experts.

> *[Interviewee #11:]"So the kinds of things that I want to see [if I had simulation models] are probably more rooted to other infrastructures, you know, the buildings, roadways, bridges [...] if I had to then bring resources in, it would also give me an idea of what I might be able to work with there. [...] But if I can't get from here to there, if there's something blocking, today I can't plan on that."*

Connecting Social Institutions and Built Environment

As discussed earlier, a significant challenge in community resilience planning is connecting built environment entities and social institutions because they mutually rely on and support each other. This is extensively described by NIST due to its critical impact on planning. However, these connections and links were not identified and considered in detail in the planning initiatives due to their extreme complexity. Simulation models can be incorporated to facilitate community resilience planning in this regard. The interviewees also mentioned this and provided some details of what they expect from simulation models to help them.

[Interviewee #8:] "If you could have a model and say "what would be the outcome if we fixed up the road system first" or what would be impacted, any buildings, there would be a lot of URM [Underrepresented Minority]. You know, what would be our payback for looking, solving, retrofitting all of our URMs versus… To be able to ask some of these questions, when these things come up for planning purposes, this is where we really ought to be …"

Communication between Built Environment and Social Institutions Experts

Experts in built environment and social institutions need to communicate and share information to make sure that decision-making comprehensively considers both dimensions and their limitations. Simulation modeling can improve this communication by simulating recovery processes based on different scenarios and providing the consequences of these scenarios for experts to analyze. Since community resilience deals with many dimensions in a community, it is likely to overlook consequences that are critically important for some experts or decision-makers. Simulation modeling helps experts to quickly and inexpensively see how the recovery process changes based on their decisions.

[Interviewee #14:] "just thinking about this idea of scenario-based thinking, if there's a way to help people sort of wargame the way these things play out. "Here's what it looks like now. We wargame. We run an exercise. We get some results. We make changes. We do it again. Hopefully we're even closer. By seeing what changes, we need to make, we're getting closer." So that kind of simulation might be intriguing."

As well, simulation modeling can help prioritize decision-making. It can provide timelines, expenses, and, more importantly, social impacts of decisions made. As a result, decision might be changed if inappropriate consequences threaten community values.

[Interviewee #8:] "One of the questions that there's no really good tool for saying, for doing scenario planning. [...] you accepted that this is risk, so what do you do with all of that? So, how much does it cost you to do all of that stuff, over what amount of time? Where should I put my dollars? What should I do first? What should I do second?"

[Interviewee #2:] "So, we're just coming up with a time, but what's not in there, I always call this the five percent problem, the standard for restoration is always ninety-five percent, but who is the five percent that doesn't get the power, and that we stop caring once we're at ninety-five percent? I want to know, you know, because I did the study in [a community in the U.S.] where I found that Hispanic populations literally were restored slower than white populations."

Information Sharing and Communication between Experts and Community Members

Effective communication and information sharing between experts and non-expert community members, or non-expert elected officials, is necessary in community resilience planning. Study participants and interviewees drew attention to the benefit of simulation modeling in this regard and mentioned how it can improve this process.

[Interviewee #7:] "I think it [community resilience planning] depends on what the community's values are going to be, but it's a tremendous opportunity to have that conversation in advance [...] a tool like what you're talking about in terms of simulation allows conversation with the board or the public or the decision makers to happen in advance, so that when the event occurs you've got some guidance in terms of how to work"

[Interviewee #7:] "More importantly, in many respects, as you go through this system planning process and the investments in the infrastructure over time to build the hardened backbone and harden the facilities, your system investments are consistent with those values and the ability to make the restoration in that kind of priority sequence."

DISCUSSION AND CONCLUSION

In this study, we identified the challenges associated with the previous community resilience planning initiatives taken place in California, Washington and Oregon. For this purpose, we interviewed experts, critical infrastructure managers, and emergency management agents who participated in the initiatives. Due to the capability of simulation modeling to address the challenges mentioned in the research studies (Ganji and Miles 2018; Miles et al. 2018), we asked the interviewees to share their opinions about how simulation modeling would support the planning initiatives and presented the findings in the previous section.

As mentioned earlier, simulation modeling is widely used in community resilience, emergency management and disaster recovery. Simulation modeling has been evolved through various approaches including (1) resource-constrained modeling, (2) machine learning, (3) dynamic economic impact modeling, (4) system dynamics simulation, (5) agent-based simulation, (6) discrete-event simulation, (7) stochastic simulation, and (8) network modeling (Miles et al. 2018). Several research studies used simulation modeling in disaster recovery of various elements of communities such as water and wastewater system (Tabucchi et al. 2010), power systems (Çağnan et al. 2006) and housing recovery (Longman and Miles 2019; Burton et al. 2017; Miles and Chang 2011). It shows the capability of simulation modeling to capture complexity of these network systems mentioned as the first challenge by the interviewees. The next challenge, the interdependencies among critical infrastructure systems, is also addressed in the literature of urban planning (Turoff et al. 2016; Banuls et al. 2013; Ouyang 2014). Integrating the built environment including buildings and critical infrastructure systems and social institutions, the forth challenge, is applied in simulation modeling of disaster recovery process (Ganji and Miles 2018).

While simulation modeling can address the first, second and forth challenges, other challenges are user-oriented and human-factors are involved. Human-centered design has the potential to address the user-oriented challenges. Human-centered design considers the concerns, values, and perceptions of all stakeholders in design of simulation models in a problem-solving process (Baxter and Sommerville 2011). Ganji and Miles (2018) presented a conceptual framework of characteristics of disaster resilience and recovery planning in two main categories including domain- and user-oriented characteristics (Ganji and Miles 2018). They argued how combining human-centered design and simulation modeling is capable to overcome not only domain-oriented challenges, but also user-oriented challenges, and proposed a conceptual framework for such models. We refer this combination as *human-centered simulation modeling*.

ACKNOWLEDGMENTS

The authors would like to thank Adele Miller for her effort in transcribing the interviews, data preparation and data cleaning. Funding support for this paper was provided by National Science Foundation Award No. 1541025.

REFERENCES

Aldrich, D. P., and Meyer, M. A. (2015). Social Capital and Community Resilience. *American Behavioral Scientist*, 59(2), 254–269.

Alipour, F., Khankeh, H., Fekrazad, H., Kamali, M., Rafiey, H., & Ahmadi, S. (2015). Social issues and post-disaster recovery: A qualitative study in an Iranian context. *International Social Work*, *58*(5), 689-703.

Burton, H. V., Deierlein, G., Lallemant, D., & Singh, Y. (2017). Measuring the Impact of Enhanced Building Performance on the Seismic Resilience of a Residential Community. Earthquake Spectra, 33(4), 1347-1367.

Banuls, V. A., Turoff, M., & Hiltz, S. R. (2013). Collaborative scenario modeling in emergency management through cross-impact. *Technological Forecasting and Social Change*, *80*(9), 1756-1774.

Baxter, G., & Sommerville, I. (2011). Socio-technical systems: From design methods to systems engineering. Interacting with computers, 23(1), 4-17.

Berkes, F., & Ross, H. (2013). Community resilience: toward an integrated approach. Society & Natural Resources, 26(1), 5-20.

Berkes, F. (2012). Understanding Uncertainty and Reducing Vulnerability: Lessons from Resilience Thinking. In C.E. Haque and D. Etkin (eds.) Disaster risk and vulnerability: mitigation through mobilizing communities and partnerships. Canada: McGill-Queen's University Press.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., ... & Von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake spectra, 19(4), 733-752.

Burton, H. V., Deierlein, G., Lallemant, D., & Singh, Y. (2017). Measuring the Impact of Enhanced Building Performance on the Seismic Resilience of a Residential Community. *Earthquake Spectra*, *33*(4), 1347-1367.

Çağnan, Z., Davidson, R. A., & Guikema, S. D. (2006). Post-earthquake restoration planning for Los Angeles electric power. Earthquake Spectra, 22(3), 589-608.

Chandra, A., Acosta, J., Howard, S., Uscher-Pines, L., Williams, M., Yeung, D., ... & Meredith, L. S. (2011). Building community resilience to disasters: A way forward to enhance national health security. *Rand health quarterly*, *1*(1).

Chang, S. E., McDaniels, T., Fox, J., Dhariwal, R., & Longstaff, H. (2014). Toward disaster-resilient cities: Characterizing resilience of infrastructure systems with expert judgments. Risk Analysis, 34(3), 416-434.

Chang, S. E., & Rose, A. Z. (2012). Towards a theory of economic recovery from disasters. International Journal of Mass Emergencies and Disasters.

Cimellaro, G. P., Renschler, C. S., Frazier, A., Arendt, L. A., Reinhorn, A. M., & Bruneau, M. (2011). The state of art of community resilience of physical infrastructures. In *Structures Congress 2011* (pp. 2021-2032).

Comes, T., & Van de Walle, B. (2014). Measuring disaster resilience: The impact of hurricane sandy on critical infrastructure systems. ISCRAM, 11, 195-204.

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1).

Cutter, S. L. (2016). The landscape of disaster resilience indicators in the USA. *Natural hazards*, *80*(2), 741-758.

Davis, C. A., Mostafavi, A., & Wang, H. (2018). Establishing Characteristics to Operationalize Resilience for Lifeline Systems. *Natural Hazards Review, 19(4),* 04018014.

Dilmaghani, R. B., Manoj, B. S., & Rao, R. R. (2006, May). Emergency communication challenges and privacy. In Proceedings of the 3rd International ISCRAM Conference.

Eid Mohamed S., and El-adaway Islam H. (2017). Integrating the Social Vulnerability of Host Communities and the Objective Functions of Associated Stakeholders during Disaster Recovery Processes Using Agent-Based Modeling. *Journal of Computing in Civil Engineering, 31(5),* 04017030.

Ganji, A., & Miles, S. (2018, October). Toward Human-Centered Simulation Modeling for Critical Infrastructure Disaster Recovery Planning. In *2018 IEEE Global Humanitarian Technology Conference (GHTC)* (pp. 1-8). IEEE.

Ganji, A., Orand, M., & McDonald, D. W. (2018). Ease on Down the Code: Complex Collaborative Qualitative Coding Simplified with 'Code Wizard'. *Proceedings of the ACM on Human-Computer Interaction*, *2* (CSCW), 132.

Gonzalez, J. J., Granmo, O. C., Munkvold, B. E., Li, F. Y., & Dugdale, J. (2012, April). Multidisciplinary challenges in an integrated emergency management approach. *In Proceedings of the 9th International ISCRAM Conference.*

Kulig, J. C., Edge, D. S., Townshend, I., Lightfoot, N., & Reimer, W. (2013). Community resiliency: Emerging theoretical insights. *Journal of Community Psychology*, *41*(6), 758-775.

Kumar, S., Diaz, R., Behr, J. G., and Toba, A.-L. (2015). Modeling the effects of labor on housing reconstruction: A system perspective. *International Journal of Disaster Risk Reduction*, 12, 154–162.

Labaka, L., Hernantes, J., Comes, T., & Sarriegi, J. M. (2014, May). Defining policies to improve critical infrastructure resilience. In *ISCRAM*.

Laugé, A., Hernantes, J., and Sarriegi, J. M. (2015). Critical infrastructure dependencies: A holistic, dynamic and quantitative approach. *International Journal of Critical Infrastructure Protection*, 8, 16–23.

Longman, M., & Miles, S. B. (2019). Using discrete event simulation to build a housing recovery simulation model for the 2015 Nepal earthquake. *International Journal of Disaster Risk Reduction, 101075*.

Lee, L., Mitchell, J., Wallace, W., (2007, November). Restoration of Services in Interdependent Infrastructure Systems: A Network Flows Approach. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), Volume: 37 , Issue: 6*.

Maitland, C., Ngamassi, L., & Tapia, A. (2009, May). Information management and technology issues addressed by humanitarian relief coordination bodies. *In Proceedings of the 6th International ISCRAM Conference.*

Miles, S. B., Burton, H. V., & Kang, H. (2018). Community of practice for modeling disaster recovery. *Natural Hazards Review, 20(1),* 04018023.

Miles, S. B. (2015). Foundations of community disaster resilience: Well-being, identity, services, and capitals. *Environmental Hazards*, *14*(2), 103-121.

Miles, S. B., and Chang, S. E. (2011). ResilUS: A Community Based Disaster Resilience Model. *Cartography and Geographic Information Science*, 38(1), 36–51.

Nejat Ali, and Ghosh Souparno. (2016). LASSO Model of Postdisaster Housing Recovery: Case Study of Hurricane Sandy. *Natural Hazards Review*, 17(3), 04016007.

NIST (National Institute of Standards and Technology). (2016). Community Resilience Planning Guide, Washington, DC. http://www.nist.gov/el/resilience/guide.cfm

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American journal of community psychology*, *41*(1-2), 127-150.

OSSPAC (Oregon Seismic Safety Policy Advisory Commission). (2013). The Oregon Resilience Plan. Salem, OR: Oregon Seismic Safety Policy Advisory Committee. February 2013. Accessed on June 19, 2018.

Ouyang, M., and Dueñas-Osorio, L. (2012). Time-dependent resilience assessment and improvement of urban infrastructure systems. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 22(3), 033122.

Poland, C. (2009). The resilient city: Defining what San Francisco needs from its seismic mitigation polices. *San Francisco Planning and Urban Research Association report, San Francisco, CA, USA*.

Ramachandran, V., Long, S. K., Shoberg, T., Corns, S., & Carlo, H. J. (2015). Framework for modeling urban restoration resilience time in the aftermath of an extreme event. Natural Hazards Review, 16(4), 04015005.

Rubim, I., Borges, R.S., (2017, May). The Resilience and Its Dimensions. In *ISCRAM*.

Semaan, B., & Hemsley, J. (2015, May). Maintaining and Creating Social Infrastructures: Towards a Theory of Resilience. In *ISCRAM*.

Scholl, H. J., and Carnes, S. L. (2017). Managerial Challenges in Early Disaster Response: The Case of the 2014 Oso/SR530 Landslide Disaster. 12.

Tabucchi, T., Davidson, R., & Brink, S. (2010). Simulation of post-earthquake water supply system restoration. *Civil Engineering and Environmental Systems*, *27*(4), 263-279.

Turoff, M., Bañuls, V. A., Plotnick, L., Hiltz, S. R., and Ramírez de la Huerga, M. (2016). A collaborative dynamic scenario model for the interaction of critical infrastructures. *Futures*, 84, 23–42.

van Laere, J., Berggren, P., Gustavsson, P., Ibrahim, O., Johansson, B., Larsson, A., Lindqwister, T., Olsson, L., and Wiberg, C. (2017). Challenges for critical infrastructure resilience: cascading effects of payment system disruptions. ISCRAM, 281–292.

WASSC (Washington State, Seismic Safety Committee). (2012). Resilient Washington State: A Framework for Minimizing Loss and Improving Statewide Recovery after an Earthquake. Olympia, WA: State of Washington Emergency Management Council Seismic Safety Committee. November 2012.

Combining a social science approach and GIS-based simulation to analyse evacuation in natural disasters: A case study in the Chilean community of Talcahuano

Susanne Kubisch
Institute of Regional Science and Center for Disaster Management and Risk Reduction Technology, Karlsruhe Institute of Technology, Germany
susanne.kubisch@kit.edu

Johanna Stötzer
Institute of Photogrammetry and Remote Sensing and Center for Disaster Management and Risk Reduction Technology, Karlsruhe Institute of Technology, Germany
johanna.stoetzer@kit.edu

Sina Keller
Institute of Photogrammetry and Remote Sensing, Karlsruhe Institute of Technology, Germany
sina.keller@kit.edu

María T. Bull
Observatory of Disaster Management, Universidad Católica de la Santísima Concepción, Chile
mbull@ucsc.cl

Andreas Braun
Institute of Regional Science, Karlsruhe Institute of Technology
andreas.braun3@kit.edu

ABSTRACT

In rapid-onset disasters the time needed for evacuation is crucial. Aside from the behaviour of the population, the road network plays a fundamental role. It serves as a medium to reach a safe area. This study analyses the entire evacuation process, from decision-making up to the arrival at an evacuation zone by combining standardised questionnaires and GIS-based simulation. Based on a case study in the Chilean community of Talcahuano, an event-based past scenario and a hypothetical future scenario is investigated, integrating the affected population in the research process. The main problem identified in past evacuations has been time delay due to congestions, which also is evident in the results of the hypothetical future scenario. A result which supports evacuation by foot. This paper argues that a combination of scientific methods is essential for analysing evacuation and to reduce the risk due to time delay, critical route and transport medium choice.

KEYWORDS Interdisciplinary approach, case study, evacuation, tsunami, recommendations, disaster risk management

CoRe Paper – Planning, Foresight and Risk Analysis
Proceedings of the 16th ISCRAM Conference – València, Spain, May 2019
Zeno Franco, José J. González and José H. Canós, eds.

INTRODUCTION

Destroyed roads and bridges, isolated road sections, past natural disasters like the Maule Earthquake and Tsunami in 2010 (Chile) and the Great East Japan Earthquake and Tsunami in 2011 illustrate the impact of natural events on critical infrastructure (Dueñas-Osorio and Kwasinski, 2012; Elnashai et al., 2010; Kadri et al., 2014; Nobuo et al., 2011). These phenomena are not isolated events. The tendency of natural disasters and their impacts on critical infrastructure are increasing (EM-DAT, 2018; Kadri et al., 2014; Munich RE, 2018; Oh, 2010). These effects are enhanced due to progressive urban development in disaster-prone areas (Chen et al., 2012). Critical infrastructure is of fundamental significance in modern societies' unobstructed functioning of day-to-day life and if disrupted, can have severe negative consequences on security and well-being (Urlainis et al., 2014). The road network, as part of the critical infrastructure, plays a crucial role in the case of natural disasters. It ensures not only the accessibility of first responders and e.g. emergency service units, but also serves as a medium for evacuation to a safe area outside the impacted area (Chen and Qiang, 2017). Hence, the importance of the road network during the evacuation is a critical issue in disaster risk management (DRM) in order to avoid loss of human life (Bunea et al., 2016).

Evacuation is the most important strategy for saving human lives, by leaving an endangered area and reaching an evacuation zone (Charnkol and Tanaboriboon, 2006; Chen et al., 2012;Shuto, 2005). Typically, natural disasters lead to the evacuation of large population masses (Buckle, 2012). Recent disasters show that the choice of transport medium in case of evacuation is the private vehicle (Lämmel et al., 2008; León & March, 2014; Pel et al., 2012; Ramos, 2016). This often leads to capacity overload and congestion on the road network (Dow & Cutter, 2002; Litman, 2006; Ramos, 2016; Rinaldi, et al., 2001). Additionally, cascading effects, occurring during tsunamis may hinder evacuation due to the blockages of intersection by the debris of destroyed buildings or collapsed electrical towers (Elnashai et al., 2010; León and March, 2014; León et al., 2018). Human behaviour in evacuation tends to be hard to predict. Many situational factors, including official warnings and instructions, time of day and day of week, the presence of family members or behaviour of the social environment, influence the decision-making process, whether to evacuate or not, and the response to an impending hazardous event. Hence, evacuation is a complex and dynamic process and may also increase the risk for the affected people (Buckle, 2012; Charnakol and Tanaboriboon, 2006; Chen, 2012; Quarantelli, 1980; Quarantelli, 1990; Ramos, 2016).

In order to execute realistic simulations and to facilitate evacuation planning, a detailed understanding of the human behaviour during evacuation, as well as an analysis of the urban environment, especially the road network, are necessary. The conditions of the road network and comprehensive knowledge about transport medium choices, elected or hypothetically elected evacuation routes and zones and the reason for the choices, may anticipate congestion and ensure effective evacuation planning (Lämmel et al., 2008; León and March, 2014; Pel et al., 2012; Ramos, 2016).

Previous evacuation studies mostly focus on either modelling approaches (Chen and Zhan, 2008; Mas et al., 2012; Pan et al., 2007) or social science approaches (Burnside et al., 2007; Dow and Cutter, 2002; Miran et al., 2018; Nakaya, et al., 2018; Perry, 1979; Shapira et al., 2018). However, the evacuation process is highly complex due to an interaction of the human factor and its urban environment. The response of the evacuees influences congestions in the road network significantly. Therefore. the evacuation process benefits from the analysis of an interdisciplinary perspective, combining different scientific methods (Chen et al., 2012; Lindell and Prater, 2007; Naster & Birst, 2010; Quarantelli, 1985). A large number of studies in the field of social science has investigated the evacuation process during hurricane events (e.g. Dash and Gladwin, 2007; Dow and Cutter 2002; Lindell et al., 2005; Smith & Mccarty, 2009; Whitehead, et al., 2000). Hurricanes have a long forewarning time. Such an evacuation differs from the evacuation process in tsunamis, where the time for evacuation decision and response is limited (Lämmel et al., 2008; León and March, 2014).

This paper addresses these limitations, linking a social science perspective and GIS (Geographic Information System) simulation, combining both fields in a stepwise research design. Besides, emphasising the value of interdisciplinary research, this paper analyses the evacuation process in a past event and hypothetical future event. The evacuation process is analysed from the decision to evacuate up to the arrival at a safe destination in case of a tsunami. The objective of the analysis is to detect issues and challenges in evacuation and to give recommendations to improve DRM at a local level. As congestion by the use of vehicles is a major problem in evacuation (León and March, 2016; Muñoz, 2014; Ramos, 2016; Riveros, 2014), evacuation by foot is simulated.

The combination of standardised questionnaires and GIS gives insight to evacuation routes and zones used and provides alternative evacuation routes by foot.

A case study is performed, investigating the district of Las Salinas, in the coastal community of Talcahuano, Chile. The community was among the Chilean coastal cities which were hardest hit by the tsunami of the 27th of February 2010 (Martínez et al., 2011).

The paper is structured as follows. The first section gives brief insight into the research area and the impacts of the earthquake in 2010 in Chile. Section 2 explains the applied methodology. In Section 3 the results are presented, followed by the discussion in Section 4. The paper finishes with a conclusion and recommendations in Section 5.

THE RESEARCH AREA TALCAHUANO

Chile is one of the countries, most prone to earthquakes due to its geographic location at the boundaries of the South American and Nazca Plates. It has a long history of tsunamis triggered by earthquakes (Bronfman et al., 2015; INE Medio Ambiente, 2010). On the 27th of February 2010, Chile was hit by an earthquake followed by a tsunami with a magnitude of 8.8 Mw, which affected about 800 km of the shoreline (Martínez, et al., 2011; USGS, 2010). According to statements of the Chilean government, more than 12.8 million people were affected by the earthquake and the subsequent tsunami, and 521 people were killed. The two most populated areas in Chile were impacted, the metropolitan region of Santiago and the central region Bio-Bío with the conurbation of Concepción-Talcahuano (CEPAL, 2010; GEER, 2010; USGS & U.S. Department of the Interior, 2011). Approximately 51% of the regional population lives in the coastal area (Martínez, et al., 2011) .

Within the region, several bridges were damaged and collapsed as a result of the earthquake. Since these bridges are critical links in the transportation network, their being damaged affected accessibility significantly. Damage to the road network was only minor. As consequences of the earthquake and tsunami, significant damage was also apparent in Talcahuano, one of the most affected communities of the tsunami in 2010 (Elnashai et al., 2010; Fritz, et al., 2010). 18.1% of the inhabitants of the community were affected and 9,173 houses were destroyed. In total, an area of 11.04 km^2 was impacted (INE, 2018; Martínez, et al., 2011). The port and the city centre were damaged severely by the tsunami, due to its low ground elevation between 5-10 m above sea level (León and March, 2014). Figure 1 illustrates the research area and an overlapping tsunami inundation map of 2010.

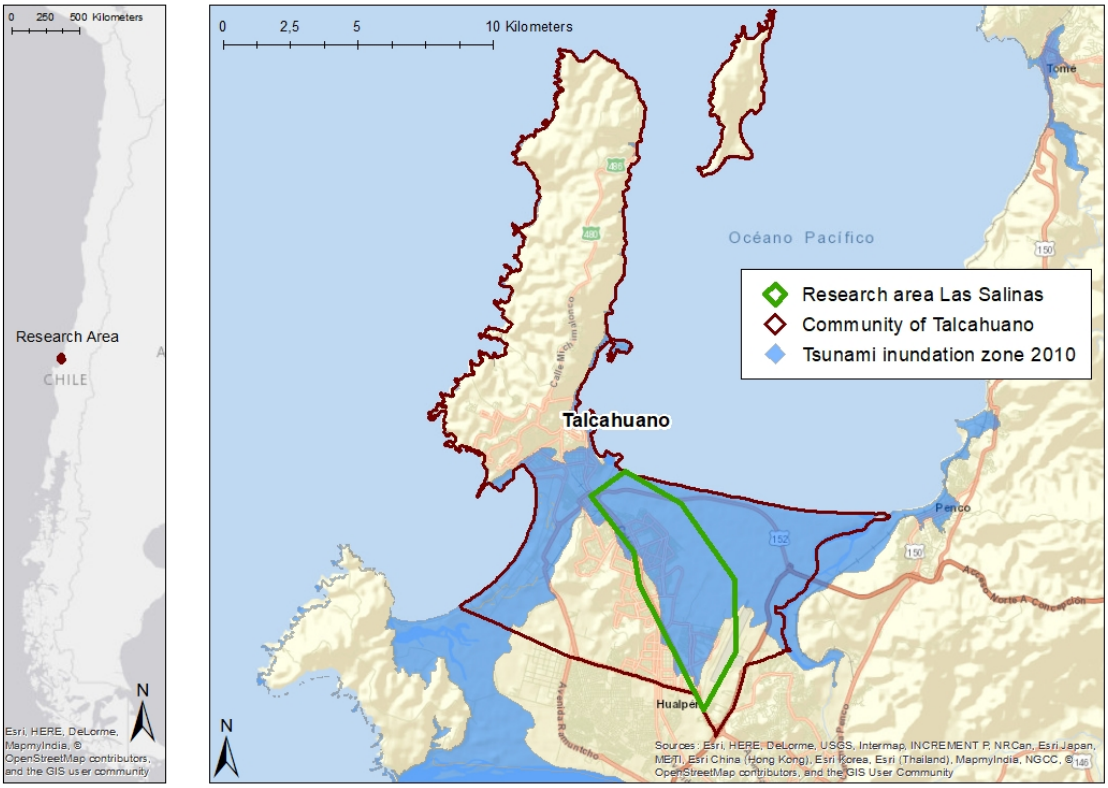


Figure 1: The Chilean territory (left), the community of Talcahuano with the research area Las Salinas and the tsunami affected area in 2010 (right).

Tsunami waves were up to 14 m high, and waves arrived between 12 to 20 minutes and 30 to 45 minutes after the earthquake, depending on the distance from the rupture zone (Vargas et al., 2010). Due to the breakdown in the communication system caused by the preceding earthquake and failures in communication between responsible institutions, no tsunami warning was released. The official institution ONEMI (Oficina Nacional de Emergencia del Ministerio del Interior y Seguridad Pública), which is responsible for the distribution of the alert, even gave a tsunami all-clear. The situation was aggravated by the centralisation of the administrative structure in Chile, which also affected the area of DRM and hindered local authorities in giving alerts. However, the majority of the coastal inhabitants left the hazard zone immediately after the earthquake (Herrmann Lunecke, 2015; León and March, 2014; Rojas et al., 2014). During that event as well as in later major earthquake and tsunami events a large part of the affected population evacuated in private vehicles. That fact led to many accidents and much congestion on the road network and impeded evacuation (León and March, 2016; Muñoz, 2014; Ramos, 2016; Riveros, 2014). The map in Figure 2 shows the official evacuation zones located 30 m above sea level and the official evacuation routes.

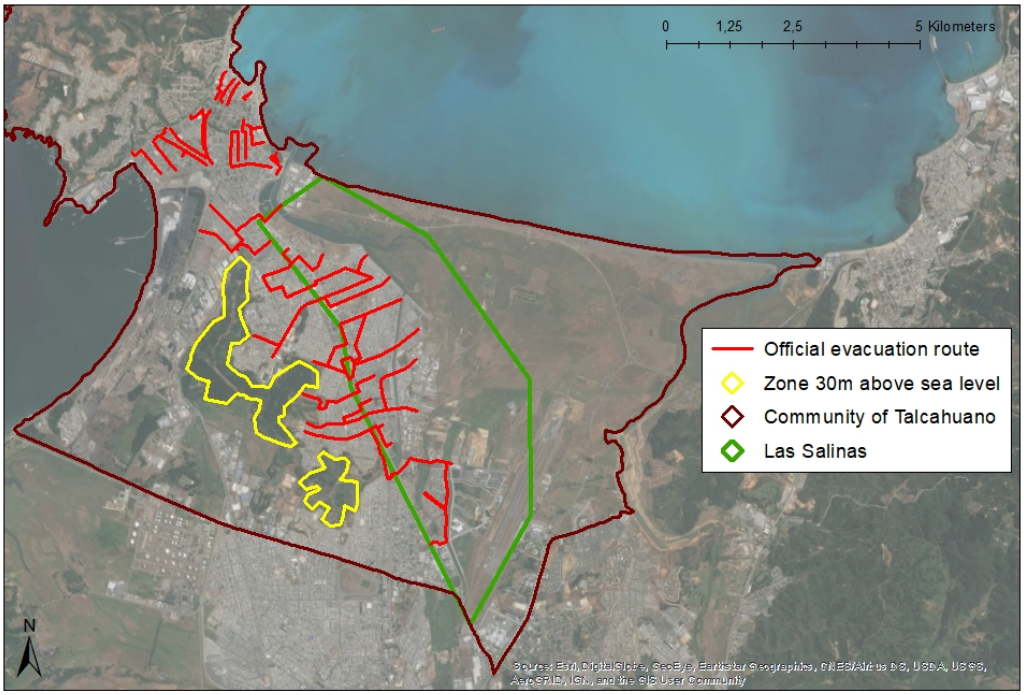


Figure 2: Official evacuation routes and zones in Talcahuano. Source: own additions based on data from Municipalidad Talcahuano (2018).

The following details are characteristics of the evacuation zones and routes of Talcahuano (see Figure 2): Evacuation zones (yellow framed area) are predominantly empty spaces and are located more or less 30 m above the sea level. An evacuation infrastructure with equipped evacuation zones is missing. The official evacuation routes and zones are marked with signs since the earthquake and tsunami of 2010. Before then, no official signposting existed (Municipalidad Talcahuano, 2018). In the following, we refer to that zone as the official evacuation zone.

METHOD

In order to analyse the evacuation process, an interdisciplinary approach was applied, combining social science and GIS simulation. We focused on the residential area of Las Salinas in the community of Talcahuano, due to the large impact there of the earthquake and tsunami event in 2010.

The research was conducted in a progressive form, the research phases were set up and linked together. Results of preceding steps were integrated in the subsequent steps. The research design can be dived in three major parts (coloured blue, green, and orange in Figure 3) with six minor phases. The first part of the social science approach represents the data collection and evaluation employing literature review, expert interviews and a standardised questionnaire. Afterwards, in the second part, a data simulation using GIS methodology was conducted. Based on the results of the preceding steps, recommendations are given.

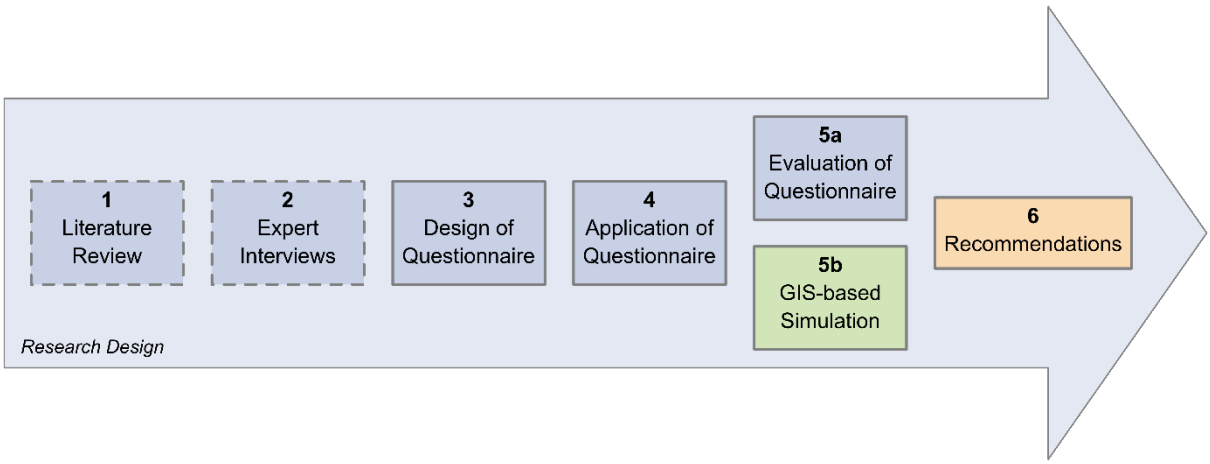


Figure 3: Overview of the research design. Steps of the social science part are highlighted in blue. The step of the GIS-based simulation is highlighted in green. Arising recommendations are highlighted in orange. Step 1 to2 in the dashed frame are not part of this paper.

Regarding the social science part of the research design, subsequent to the literature review on evacuation research, DRM, and state of the art in Chile, guided expert interviews were executed. Thereafter, Chilean experts of DRM, urban and regional planning, psychology and sociology were consulted. The results of the literature review and the expert interviews served as a basis for the design of the standardised questionnaires, which were distributed in the research area. After the application of the questionnaires, the results are statistically evaluated. The results from the marked maps, which were part of the questionnaire, were then integrated into and visualised with a GIS. In order to face the critical issues identified by means of the standardised questionnaire, further simulations were executed to perform a possible simulation by foot. On the basis of the results of both approaches, recommendation for strengthening DRM in the research area are given. In the following, the procedure of the survey, as well as the GIS simulation are explained in more detail.

The survey process

The standardised questionnaire was applied in the district Las Salinas on a household level. In total, 136 households were surveyed (N=136). The households were reached via the leaders of the *Juntas de Vecinos*, which are neighbourhood communities, uniting several times a year to discuss relevant problems and challenges within the district. The respective *Juntas de Vecinos* are spatially distributed within the district, so that the questionnaires were evenly distributed.

The questionnaire was comprised of eight parts. In the first part, socio-economic data were collected. The second part queried the experience with tsunamis and the impact on the household's property. The third and the fourth parts of the questionnaire collected data about influencing factors in the decision of evacuation and about the evacuation undertaken in the tsunami event in 2010. The fifth part requested the destination of evacuation in 2010. The sixth and the seventh parts was comprised of a combination of maps and questions. The respondents had to indicate the evacuation routes and zones they used in 2010 and respond to questions about the kind of blockages they discovered in the road network, as well as their transport medium choice. The seventh part collected data about evacuation behaviour in a possible future tsunami event, indicating possible evacuation routes and zones. The last part contained questions about the evaluation of DRM at the local and national level. The questionnaire was composed predominantly of closed questions with one or more predetermined answers possible. Respondents who did not evacuate in 2010 or had not been in the research area at the time the tsunami struck the area could mark the option "I did not evacuate".

The questionnaire, which was carried out in Spanish, was analysed with a frequency distribution using IBM SPSS Statistics 24. The results of the maps were integrated into QGIS, in order to visualise the past and future evacuation routes and zones.

GIS-based simulation of evacuation routes

For the GIS simulation, the OpenStreetMap (OSM) road network data was employed (OSM Contributers, 2018). OSM is crowd-sourced and free to use under an open license. The quality of OSM data varies between regions. A preliminary manual analysis of the road network data for the study region in Talcahuano has proven that the accuracy and completeness of the OSM data are sufficiently high.

The GIS served to evaluate and visualise the maps of the recent event-based and hypothetical future scenario of evacuation routes and zones which were marked by the respondents in the standardised questionnaire. In a further step, alternative simulations of the shortest footpaths to the nearest evacuation zones were conducted and evacuation time for walking distance to these zones was simulated for different walking speeds.

For the simulation of evacuation routes, 50 access points or roads to the evacuation zones were identified visually with the help of Google Maps satellite data. In a few cases, access points are roads that lead to the evacuation zone. In most cases, the access points to the evacuation zone are small, muddy footpaths. These points are herein called evacuation zone access points (EZAP).

The typical walking speed of pedestrians depends on multiple factors like age, disability, gender, road conditions and group size (Gates et al., 2006). In addition to these factors, the walking speed in disaster scenarios is even more unpredictable. For this simulation walking speeds were used that were observed during a simulated tsunami evacuation in Padang, Indonesia by Yosritzal et al. (2018). They observed different walking speeds for various age groups. Using their findings, three different walking speeds were applied for different age groups in this study: slow (1.35 m/s) for children under 10 years old, medium (1.4 m/s) for elderly, older than 60 years and fast (1.51 m/s) for adults between 40 and 60 years. The simulation did not consider the slope of the terrain as a factor on the walking speed.

Data on the exact location of households in Talcahuano does not exist. Thus, to obtain the starting points for the shortest path calculation to the evacuation zones, a 10 m x 10 m grid over the study region was created. The centroids of the grid cells served as starting points for the evacuation routes. Only centroids that are closer than 200 m to a road were considered for the simulation. This results in a total of approximately 180.000 starting points in the area. Then the shortest walking path via the OSM road network to the next road near an EZAP is calculated from every grid cell. For the shortest path calculation, the Dijkstra Algorithm (Dijkstra 1959) was applied. The distances from the centroid and from the EZAP to the nearest road, respectively, were added to the shortest path distance. Additionally, for every road in the network it was counted how often it is travelled. For every EZAP it was evaluated for how many starting points it is the closest.

The simulation was done using the open-source object-relational database PostgreSQL (v. 9.3) and its extension PostGIS (v. 2.3). pgRouting (v. 2.4) provides geospatial routing and other network analysis functionality. Results are illustrated with the GIS software QGIS (v. 2.18).

RESULTS

The result section is divided into two parts. According to the structure of the research design, the results of the standardised questionnaire are presented first, followed by the results of the GIS-based simulation.

Results of the survey

The results of the survey are divided into a past event and a hypothetical future scenario, and are structured in the sequence of an evacuation process, from the decision to evacuate to the arrival at the destination of evacuation. The results are based, as mentioned before, on N=136 households surveyed.

According to the results of the survey, in 2010 72.1% of the respondents evacuated, 22.8% of the interviewed person decided against evacuation or had not been in the research area at the time of the earthquake, and 5.1% did not answer the question.

The respondents were asked to indicate which factors they considered in their decision to evacuate *(multiple answers possible)*. The majority specified the intensity of the previous earthquake (58.8%) as critical for the decision to evacuate. Further factors relevant for the decision were the distance to the evacuation zone (23.5%),

availability of a car (19.1%), withdrawal of the sea (16.2%) and the evacuation of family and neighbours (14.7%). All relevant factors are illustrated in Figure 4.

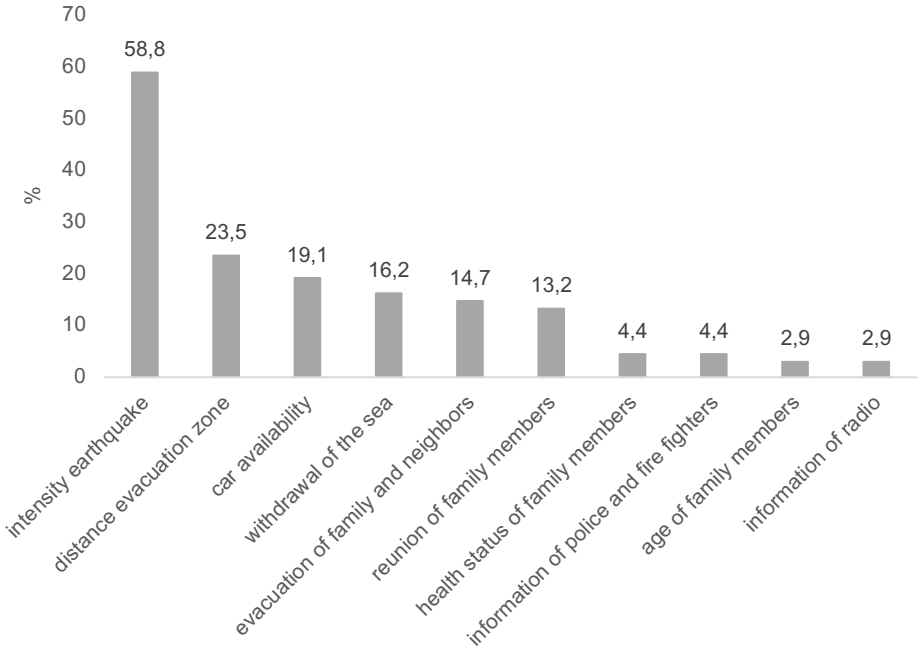


Figure 4: Factors of the decision of evacuation in 2010.

To decide whether to evacuate or not, 30.9% of the respondents indicated to have needed up to 5 minutes, 21.3% up to 10 minutes, whereas 10.3% took more than 25 minutes for their decision (Figure 5).

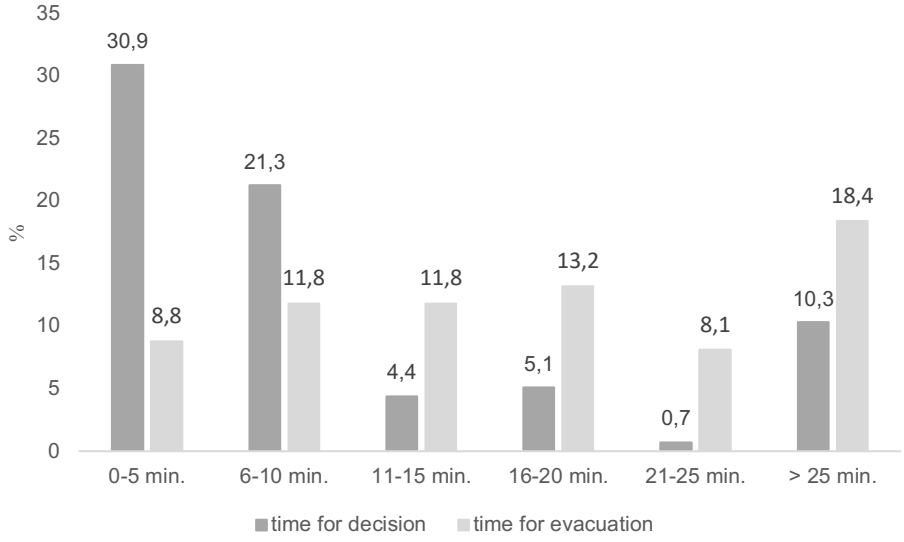


Figure 5: Time of decision-making and evacuation in the event 2010.

As a next step after making the decision to evacuate, 33.1% of the respondents collected equipment essential for survival, 27.2% tried to reunite their family and 19.9% tried to communicate with their family, and 14.7 % with their neighbours. Only 8.1% tried to get information from authorities *(multiple answers possible)*.

Finally, 59.6% evacuated with their whole family. In a hypothetical future scenario, if the family would not be together *(multiple answers possible)*, the majority (71.3%) indicated they would evacuate with present family

members. Another 27.2% indicated they would bring together all family members and 27.2% retrieve their children from kindergarten or school.

The primary transport medium for evacuation in 2010 was the private car with 52.2%, and only 17.6% indicated having evacuated by foot. The primary reason for choosing the car was speed (26.5%), followed by the presence of children and older adults (24.3%). Further, the distance to the evacuation zone (20.6%) and the possibility to overnight in the car (18.4%) were mentioned. Expected blockages and congestion (10.3%) in the road network was the fifth most common answer *(multiple answers possible)* (Figure 6).

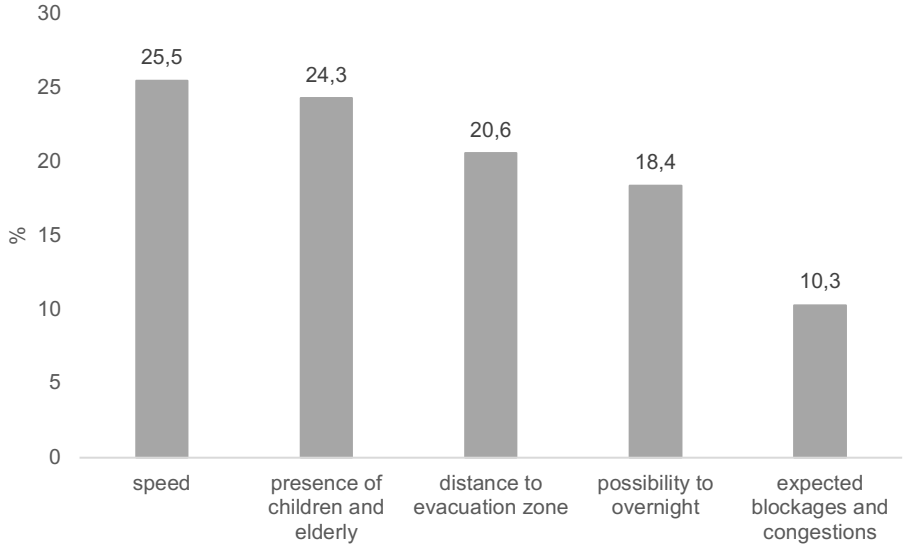


Figure 6: Reasons for the choice of transport medium.

Asking the respondents for a hypothetical future scenario, 46,3% indicated they would evacuate by car, while almost the same number (43,4%) would evacuate on foot.

Most of the evacuees (18.4%) needed more than 25 minutes to reach a safe destination, and many more needed up to 20 minutes (13.2%). Only a minority (8.8%) indicated to have needed as little as 5 minutes (Figure 5). The main reasons for the amount of time needed to evacuate were blockages (47.1%) in the road network and the distance to the evacuation zone (22.8%). The roads were mainly blocked by congestion (39.7%), persons in the street (38.3%), parked cars (21.3%) and debris (14.7%) due to the preceding earthquake *(multiple answers possible)*.

Figure 7 illustrates the evacuation routes and zones in 2010 (left) and in a hypothetical future event (right), which were indicated by the respondents on the maps. The thicker a street is highlighted the more evacuees have used it in 2010 or would use it in a hypothetical future event.

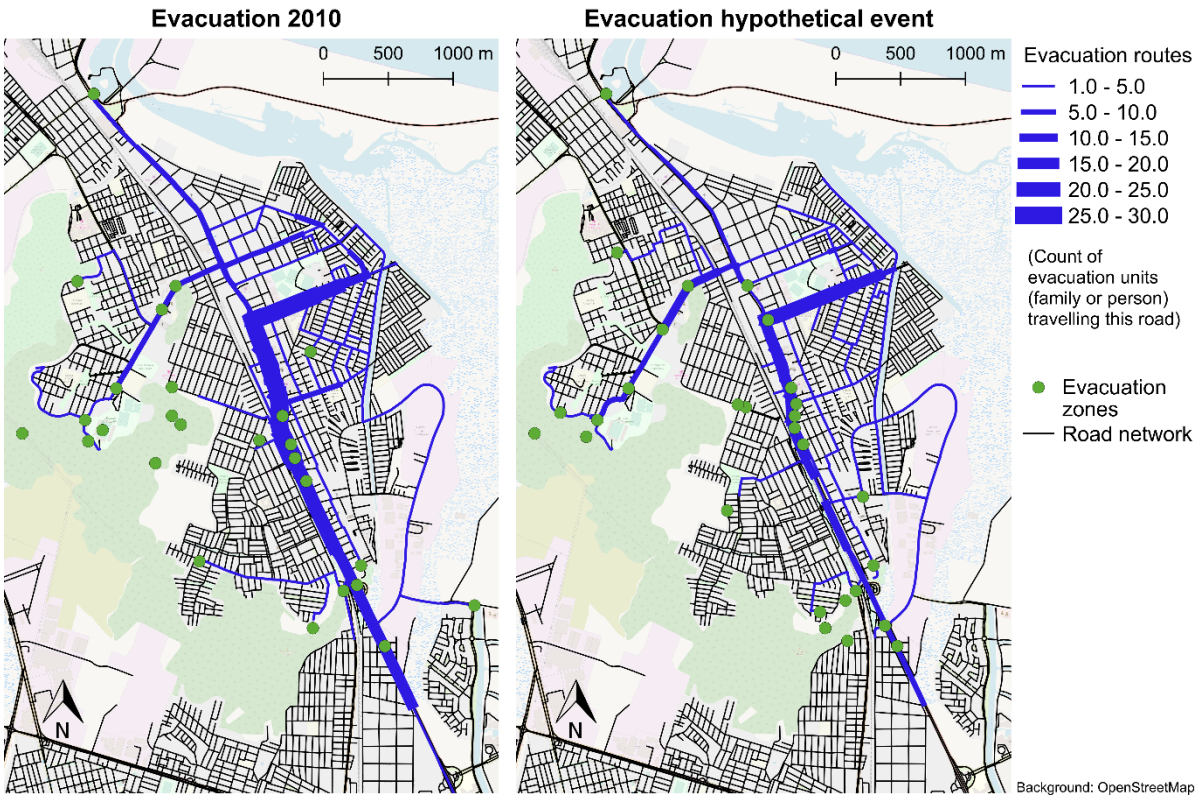


Figure 7: Evacuation routes and zones in 2010 (left), and in a hypothetical future event (right).

The majority of the evacuees indicated that they chose the route for evacuation that they are most familiar with (42.6%), or the route they consider to be the safest (17.6%), or is the shortest route to the evacuation zone (11.8%). Estimated congestion and blockages (9.6%) were not that relevant in evacuation route choice. In a hypothetical future scenario, the main reason for evacuation route choice is familiarity (58.1%). The evaluated distance to the evacuation zone (30.9%) and route security (20.6%) gain in importance for the choice, as does congestion and blockages (22.8%) *(multiple answers possible)* (Figure 8).

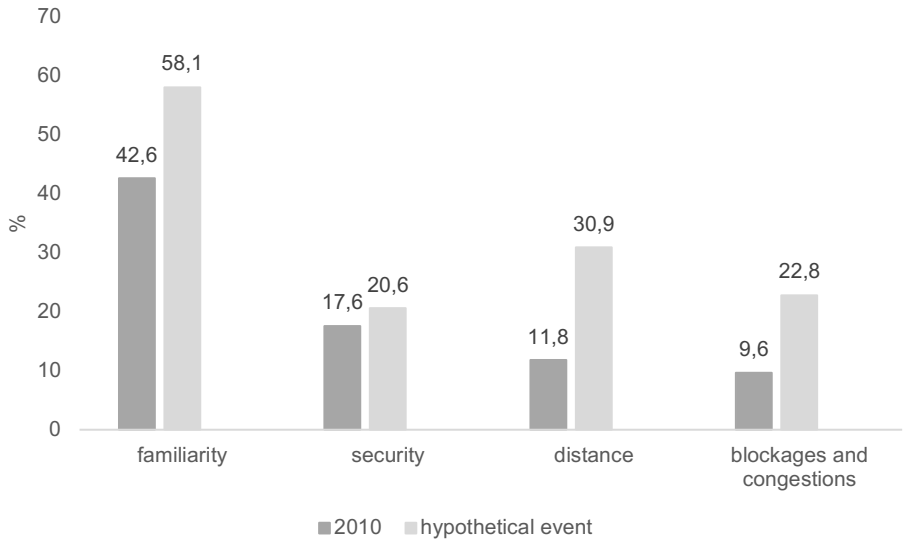


Figure 8: Reasons for the choice of the evacuation route in 2010 and in a hypothetical future event.

Regarding the destination for evacuation in 2010, most of the respondents indicated that they chose a nearby hill for evacuation (52.2%) or went to family or neighbours (8.8%). Reasons given were mainly the proximity to the house (26.5%) and accessibility (25.7%) *(multiple answers possible)*. In a hypothetical future scenario, the respondents indicated that they would go to the evacuation zones in Figure 7. Reasons are in particular the evaluation of the security of the zone (30.9%), the proximity to the house (30.1%), and evacuation zones which are recommended by authorities (22.1%). Also, accessibility (16.2%) would play a role in the choice. Recommendation by friends and family members (11%), as well as crowdedness (11%) would play a subordinate role. The facilities (shelter etc.) at the evacuation zone (2.9%) are rarely critical for the choice *(multiple answers possible)*.

Many respondents drove outside the community in 2010, so some evacuation zones are located outside the map extract in Figure 7 (left).

Results of the GIS-based simulation

The results of the walking time estimation for the three walking speeds described above are presented in Figure 9. A total area of circa 19.2 km^2 in Las Salinas was simulated. With a slow walking speed, 46.5% of the area needs an evacuation time over 15 minutes. With a medium walking speed, this decreases to 45.5% and to 43.3% with a fast walking speed. A small percentage (of 9.6% at slow speed, 7.4% at medium speed, and 4.2% at fast speed) of the area takes longer than 30 minutes (red marked area) to evacuate by foot. These results base on the assumption that the evacuees follow the shortest path to the nearest evacuation zone.

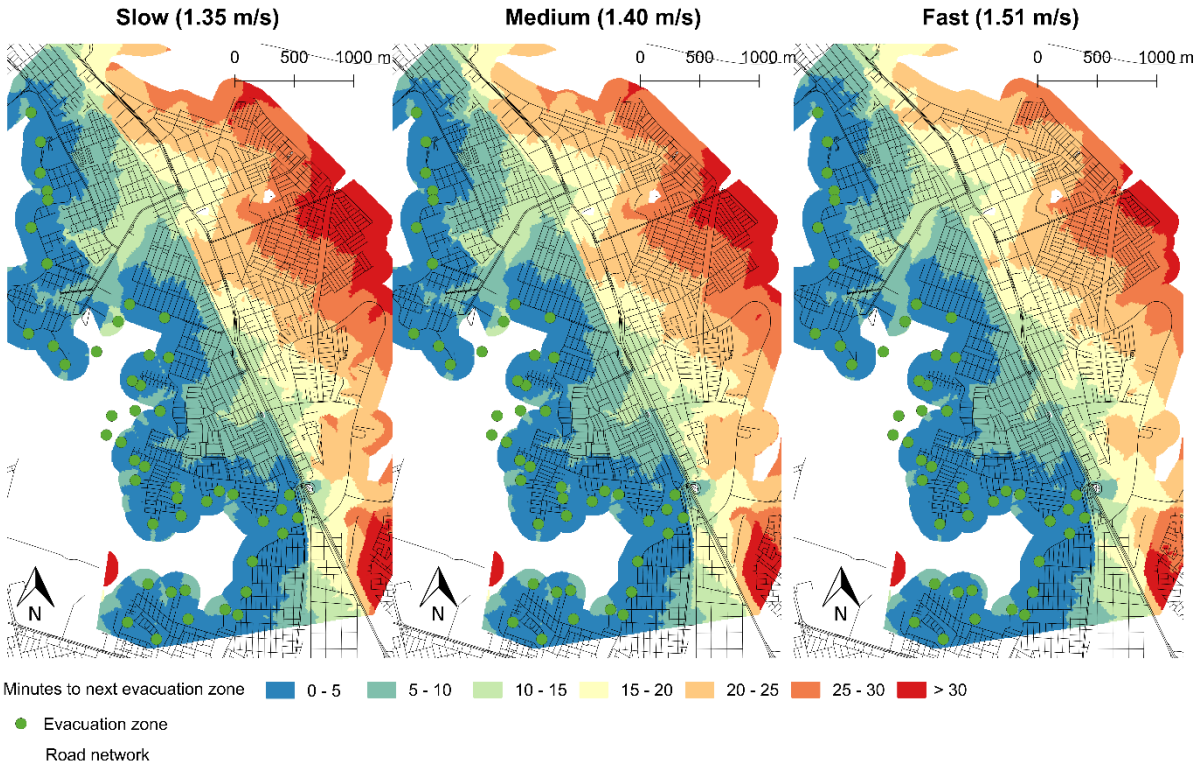


Figure 9: Evacuation times in minute for slow, medium and fast walking speed.

Figure 10 illustrates which roads and which EZAP are most used for evacuation. In total, 192.249 shortest evacuation paths were calculated. The four most often used EZAP are the nearest EZAP for 57% of the area.

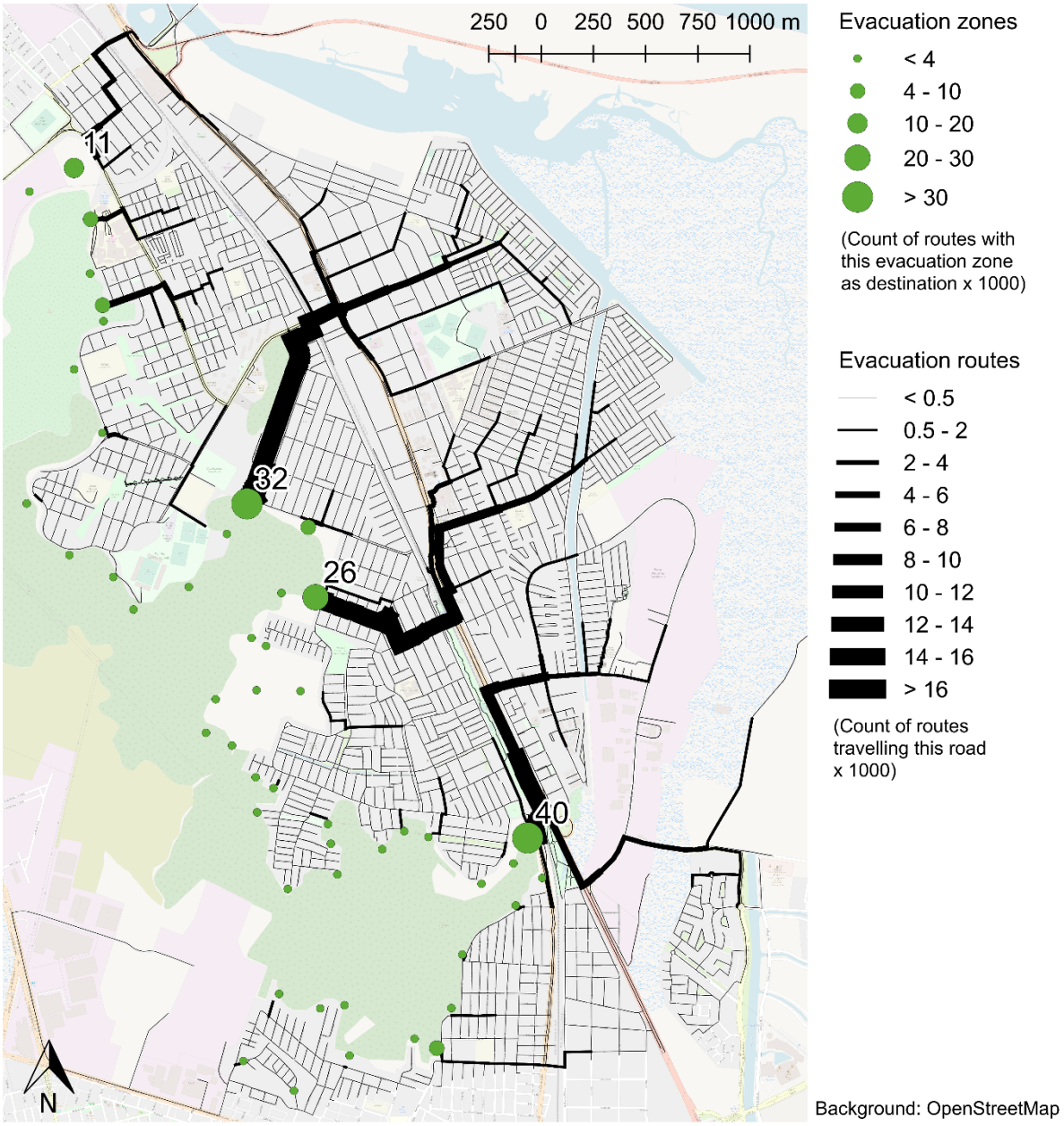


Figure 10: Most used evacuation routes and evacuation zones in Las Salinas.

Figure 10 reveals three main evacuation corridors for the inhabitants of Las Salinas.

DISCUSSION

The results of the case study reveal that irrespective of a lack of official information and the all-clear of a tsunami by responsible authorities in 2010 (Rojas et al., 2014), the majority of the respondents evacuated mostly because of the intensity of the prevenient earthquake. This behaviour may arise out of risk awareness due to past experiences.

However, despite the autonomous response of the affected population, the reported time needed for evacuation in 2010, which was a combination of the time taken for decision-making, actions for preparing the evacuation, and travel to the evacuation zone, was critical, bearing in mind that the first tsunami waves arrived 12-20 minutes after the earthquake in some coastal locations (Vargas et al., 2011). Although the majority decided within 5 minutes whether to evacuate or not, 10.3% indicated to have taken more than 25 minutes for the decision, a time period which might be critical in a hazardous event, in which time for response is limited. The delay in decision-making

may be traced back to uncertainty, due to the all-clear of tsunami by responsible authorities (Rojas et al., 2014). This delay is even longer when summing up time needed to prepare for the evacuation, including reuniting family members. Although it did not pose a problem in 2010, because the tsunami took place at night and in vacation time when most of the family members were together, the reunion of the family might become a critical issue in a hypothetical future scenario. The results revealed that the respondents would pick up their children from kindergarten or school, which both increases the time needed for evacuation and might lead to blockages of street sections due to congestion by contraflow, which might even be directed into the hazard-prone area, where many kindergartens and schools are located. Consequently, increasing traffic volume might additionally raise total evacuation time, from leaving the home until the arrival at the evacuation zone, which already took more than 25 minutes in most of the cases in 2010. Besides congestion due to car use as main transport medium, the distance to the evacuation zone posed a critical issue in evacuation time in 2010.

In order to reduce evacuation time due to congestion by car use, a GIS simulation was executed, identifying the shortest possible footpaths to the nearest evacuation zones (Figure 9). The simulation considered walking speeds of different age groups. The results demonstrate that at the east end of the research area, more than 40% of the evacuees of the area, in each speed category, would need more than 15 minutes to evacuate by foot. Consequently, the evacuees would not make it walking to the nearest evacuation zone before the first tsunami waves arrived. In 2010 the first tsunami waves arrived in some coastal locations after a few minutes. Additionally, 9.6% of the area for slow walking speed, including children under 10 years and 7.4% of the area for medium walking speed, would need more than 30 minutes to evacuate to the nearest evacuation zone. Consequently, the preference for use of the car as transport medium in evacuation in the research area becomes understandable. The indicated reasons for car use in the questionnaire, which are velocity, the presence of children and seniors and the distance to the zone, reinforce these findings. Although according to the indications the number of evacuees evacuating by foot would increase in a hypothetical scenario compared to 2010, more than half of the respondents indicate they would evacuate by car. Another reason that favours the evacuation by foot is the accessibility to the evacuation zones, since the roads are in most of the cases muddy footpaths and blocked by fences which could not be passed by car.

Comparing the evacuation route and zone choice in both scenarios (Figure 7), the main road, which crosses Talcahuano from south to north and leads outside of the community, is the primarily road chosen for evacuation. Comparing the roads chosen in the past and the hypothetical future scenario, they do not coincide with the official evacuation routes, which lead up the hills to the yellow framed evacuation zone in Figure 2, even when 22.8% indicate that the recommendation of the evacuation zone by authorities is relevant for future choice. Also, the factor of proximity to the evacuation zone gains in importance in a future scenario, however the majority would evacuate to zones outside the community according to the indications in the map. This may argue for a lack of knowledge of official evacuation routes and zones. On the other hand, knowing that the main reason for route choice is the familiarity with the route, it becomes understandable. Official evacuation routes lead just up to the hills, where no infrastructure for daily needs is located and land use is mostly dedicated as residential area. In contrast, the main road leads outside the community in direction to the next biggest city Concepción, which provides infrastructure for daily needs and workplaces. Expected congestion and blockages influenced the choice to a small degree in 2010; however, the importance of this factor in route choice gains importance in the hypothetical future scenario. Nevertheless, despite the awareness of possible congestion, the respondents indicated the same route in a hypothetical scenario.

Furthermore, as the distance of the evacuation zone was a major factor in transport medium choice, in order to detect if evacuating by foot would be an alternative, the shortest paths for walking out of the inundation zone to the nearest evacuation zone have been simulated. The simulation results show three main evacuation corridors and one minor evacuation corridor (Figure 10). Four major access points to evacuation zones are identified, which serve as a destination for 57% of the shortest evacuation routes. However, it has to be noted that these identified evacuation zones are just empty areas up the hill, which do not provide shelter and are not equipped with essential supplies like beds, food, water and medicine for evacuees. Additionally, if all households would evacuate to these areas, the capacity might be exceeded. Furthermore, the nearest paths which lead to the identified zones are particularly small muddy roads which are not paved and may not satisfy the demand in case of evacuation. Additionally, fences of private estates and the trail rail line along the main road might hinder evacuation to these zones. Examining the results of the shortest paths, those do not coincide with the results in the standardised questionnaires for the hypothetical and past scenario (Figure 7). However, they coincide with the official

evacuation routes Figure 2. Furthermore it has to be acknowledged that those evacuation zones will not be reachable for all evacuees in a short time period (see Figure 9).

CONCLUSION AND RECOMMENDATIONS

This research points out three critical issues in evacuation, identified by an analysis of a past and a hypothetical future event, integrating the affected population by means of a standardised questionnaire. These issues, namely evacuation time, distance to the evacuation zone, transport medium choice and congestions in the road network, are underpinned by the results of the GIS simulation.

The research highlights that these critical issues identified depend on one another. Given that the evacuation zones on the hills are, according to the indications in the questionnaire, too far away, the main transport medium in evacuation was and will be the car. This is fortified by the GIS analysis, which illustrates that the evacuation zones are particularly not reachable within a few minutes by foot. Familiarity was the main reason for route choice. Most of the evacuees used and will use the main road, which they use daily, resulting in congestions which increases time needed for evacuation starting from leaving the house to reaching the evacuation zone. Consequently, if the urban environment will not be adapted to the case of evacuation, e.g. build evacuation zones within the research area (see f. e. Ramos, 2016), it is questionable if in a future event, transport medium choice will change. Hence, time delay in evacuation will continue and may even be aggravated by the fact, that if a future event happens on a weekday during the day, a high percentage of the population will first pick up their children from kindergarten and school. Furthermore, the official evacuation zones on the hills, which are also identified in the GIS simulation, modelling the shortest path to the nearest evacuation zone, are not equipped with shelters and supplies like water, food, medicine and beds and are sometimes only reachable by small muddy footpaths with impediments like railroad lines or fences of private estate, which might also be a reason for not using the evacuation routes and zones heading to the hills. Even if evacuating by foot would be promoted, the nearest evacuation zones, identified in the GIS simulation, would not satisfy the capacity needed for the number of evacuees. Further, it has to be considered, that the car also provides a shelter in case of evacuation.

In order to alleviate the critical issues identified, we recommend short- and long-term measures to strengthen DRM at local level. As a short-term measure, raising awareness regarding transport medium and evacuation route and zone choice, we recommend workshops for the affected population, which would be guided by the leaders of the *Juntas de Vecinos* and local authorities responsible for DRM and urban planning. In these workshops the critical issues in evacuation, time delay, transport medium and evacuation route and zone choice should be discussed. At the end of the workshops, every household should be provided with an emergency kit and a family emergency plan, which includes strategies in evacuation. The latter should include where to meet absent family members, and which evacuation route and zone to use. The distribution of evacuation routes and zones within the *Juntas de Vecinos* should alleviate traffic flow in evacuation. These workshops should be repeated once a year, so that changes in the urban environment and human behaviour can be considered. Furthermore, the results of the workshops could be integrated in an online platform of the municipality, in order to be available for daily use to the community. The online platform should be updated by the responsible disaster managers and enriched with data of further municipality departments, such as road construction.

In order to promote evacuation by foot in the long-term, as pointed out in this research, hard measures are needed. The urban environment has to be adapted to the necessities in the case of emergency. Besides the signage of the designated evacuation routes and zones in the workshops with the *Juntas de Vecinos*, the evacuation zones have to be equipped with shelters, which would provide capacity for a certain number of evacuees and provide essential supplies. Additionally, this paper provides (see Figure 10) the nearest footpaths in the research area to the nearest evacuation zones on the hills. However, the accessibility to these zones has to be improved, removing impeding elements like fences. Furthermore, evacuation routes have to be paved and extended if necessary. Further, experts have to be aware of the scarce capacity of the nearest zones identified in this research, as they have to accommodate more than 57% of the households. Consequently, alternative routes and zones have to be provided. If evacuation by foot should be promoted, the long-term measures are indispensable. Those include as well possibilities for vertical evacuation in Las Salinas (see f. e. Ramos, 2016), given that the residents at the east end of the area would not make it walking in case of a near-field tsunami. The same is valid for families with children and seniors.

Additionally, in order to avoid counter-evacuation traffic flow, it is recommendable to relocate kindergartens and schools to evacuation zones. Furthermore, these might provide shelters in case of emergency and consequently have a multifunctional use.

This research highlights the necessity of the combination of a social science approach and GIS simulation, integrating the affected population. As the research showed, the standardised questionnaire provides insight into critical issues in a past event-based and a hypothetical future scenario. The GIS-based simulations integrate on the one hand the results of the questionnaires and provide on the other hand results of the evacuation by foot. Thus, critical issues detected by the questionnaire are faced and underpinned. The combination of the results ensures an effective evacuation planning. Disaster managers and urban planners might benefit from the results. Of course both approaches have limitations. Since the event in 2010 was seven years before the research was executed, the respondents to the questionnaire might not remember every detail of the evacuation. Additionally, the indication for the future scenario is hypothetical, so that the results contain assumptions about future choices. A limitation of the GIS simulation is that the topography of the research area, which might influence walking speed, is not considered.

Future research may consider the advantages of the application of interdisciplinary approaches, but also consider the limitations which are discussed above. The research design applied in this study can be transformed to other Chilean coastal communities, as they face similar problems and share the same social, ecological and political background. In order to apply this approach to other countries and other natural disasters, the specific context has to be considered, and the social science approach, especially the standardised questionnaire, has to be adapted to this context. It would be interesting to integrate further data collected by the standardised questionnaire, like the period of time in which the evacuation started. A (multi-)agent-based system might consider this valuable data and also consider the critical issue of contraflow, fetching the children from kindergarten and school (f.e. Mas et al., 2012).

Evacuation reduces the risk for the affected population during natural disasters, however, the evacuation might be more effective, if time delays and congestions are considered in preparation measures and strategies of DRM. Therefore, it is argued that a more detailed analysis can only be conducted if the strengths of different scientific approaches are combined, analysing human behaviour in the evacuation process as well as investigating the linkages to the road network and the urban environment, which play a crucial role in evacuation.

ACKNOWLEDGEMENT

We are grateful to Boris Sáez Arévalo, director of the department of risk management of the municipality of Talcahuano, and to his colleagues in supporting us with information, data and in the distribution of the questionnaire.

REFERENCES

Bronfman, N., Cisternas, P., López-Vásquez, E. and Cifuentes, L. (2015). Trust and risk perception of natural hazards: implications for risk preparedness in Chile. *Natural Hazards*, 81,1, 307-327.

Buckle, P. (2012). Preparedness, warning and evacuation. In B. Wisner, J. Gaillard, & I. Kelman, *The Routledge Handbook of Hazards and Disaster Risk Reduction* , 493-504. Oxon: Routledge.

Bunea, G., Leon, F. and Atanasiu, G. (2016). Postdisaster Evacuation Scenarios Using Multiagent System. *Journal of Computing in Civil Engineering,* 30, 6 , 05016002-1-05016002-10.

Burnside, R., De Monde Miller, S. and Rivera, J. (2007). The impact of information and risk perception on the hurricane evacuation decision-making of Greater New Orleans residents. *Sociological spectrum*, 27, 727–740.

CEPAL. (2010). *Terremoto en Chile - Una primera mirada al 10 de marzo 2010.* Santiago de Chile: United Nations. Retrieved 11 13, 2018, from https://www.cepal.org/es/publicaciones/32838-terremoto-chile-primera-mirada-al-10-marzo-2010.

Charnkol, T. and Tanaboriboon, Y. (2006). Tsunami Evacuation Behavior Analysis - One Step of Transportation Disaster Response. *IATSS Research,* 30, 2, 83–96.

Chen, X. and Qiang, L. (2017). Modeling Road Network Vulnerability for Evacuees and First Responders in No-Notice Evacuations. *Journal of Advanced Transportation*, 1-12.

Chen, X. and Zhan, F. (2008). Agent-based modelling and simulation of urban evacuation: relative effectiveness of simultaneous and staged evacuation strategies. *Journal of the Operational Research Society,* 59, 1, 25-33.

Chen, X., Kwan, M.-P., Li, Q. and Chen, J. (2012). A model for evacuation risk assessment with consideration of pre- and post-disaster factors. *Computers, Environment and Urban Systems,* 36, 3, 207–217.

Contributors, O. S.M. (2018). *Open Street Map*. Retrieved from https://www.openstreetmap.org

Dash, N., and Gladwin, H. (2007). Evacuation Decision Making and Behavioral Responses: Individual and Household. *Natural Hazards Review,* 8, 3, 69-77.

Dijkstra, E. (1959). A note on two problems in connexion with graphs. *Numerische Mathematik,* 1, 1, 269-271.

Dilley, M., Chen, R., Deichmann, U., Lerner-Lam, A., Arnold, M., Agwe, J., . . . Yetman, G. (2005). *Natural disaster hotspots: A global risk analysis.* Washington D.C., USA: World Bank.

Dow, K. and Cutter , S. (2002). Emerging Hurricane Evacuation Issues: Hurricane Floyd and South Carolina. *Natural Hazards Review,* 3, 1, 12-18.

Dow, K. and Cutter, S. (1998). Crying wolf: repeat responses to hurricane evacuation orders. *Coastal Management*, 26, 237-251.

Drabek, T. (1986). *Human systems responses to disaster: An inventory of sociological findings.* New York: Springer.

Dueñas-Osorio, L. and Kwasinski, A. (2012). Quantification of Lifeline System Interdependencies after the 27 February 2010 Mw 8.8 Offshore Maule, Chile, Earthquake. *Earthquake Spectra,* 28, 1, 581-603 .

Elnashai, A., Gencturk, B., Kwon, O., Al-Qadi, I., HashashY., Roesler, J., . . . Valdivia, A. (2010). *The Maule (Chile) Earthquake of February 27, 2010: Consequence assessment and case studies.* Mid-America Earthquake Center. Retrieved 11 15, 2018, from https://www.ideals.illinois.edu/handle/2142/18212.

EM-DAT. (2018). The International Disaster Database . (C. o. CRED, Ed.) Brussels, Belgium. Retrieved 07 18, 2018, from https://www.emdat.be/.

Farías, M., Vargas, G., Tassara, A., Carretier, S., Baize, S., Melnick, D. and Bataille, K. (2010). Land-Level Changes Produced by the Mw 8.8 2010 Chilean Earthquake. *Science*, 329, 916.

Gates, T., Noyce, D., Bill, A. and van Ee, N. (2006). Recommended Walking Speeds for Timing of Pedestrian Clearance Intervals Based on Characteristics of the Pedestrian Population. *Transportation Research Record*, 1, 38-47.

GEER, G. (2010). *Geo-engineering reconnaissance of the February 27, 2010, Maule, Chile, earthquake.* GEER Association. Retrieved 11 12, 2018, from http://www.geerassociation.org/component/geer_reports/?view=geerreports&id=44&layout=build.

Herrmann Lunecke, M. (2015). Urban planning and tsunami impact mitigation in Chile after February 27, 2010. *Natural Hazards*, 79, 1591-1620.

Houser, C. (2009). Geomorphological Controls on Road Damage During Hurricanes Ivan and Dennis. *Journal of Coastal Research,* 25, 3, 558-568.

INE. (2010). *Medio Ambiente - Informe Anual 2010.* Santiago de Chile: Instituto Nacional de Estadística Chile. Retrieved 11 12, 2018, from www.ine.cl/docs/default-source/publicaciones/2012/medioambiente_2010_160212.pdf?sfvrsn=4.

INE. (2018). *Instituto Nacional de Estadísticas.* Santiago de Chile. Retrieved 11 12, 2018, from http://www.ine.cl/.

Kadri, F., Birregah, B. and Châtelet, E. (2014). The Impact of Natural Disasters on Critical Infrastructures: A Domino Effect-based Study. *Journal of Homeland Security and Emergency Management,* 11, 2, 217–241.

Lämmel, G., Rieser, M. and Nagel, K. (2008). Bottlenecks and Congestion in Evacuation Scenarios: A microscopic evacuation simulation for large-scale disasters. *5th Workshop on Agents in Traffic and Transportation (ATT) @ Autonomous Agents and Multiagent Systems (AAMAS) '08*, 1-8.

Lämmel, G., Rieser, M., Nagel, K., Taubenböck, H., Strunz, G., Goseberg, N., . . . Birkmann, J. (2008). Emergency Preparedness in the case of a Tsunami - Evacuation Analysis and Traffic Optimization for the Indonesian city of Padang. In W. Klingsch, C. Rogsch, A. Schadschneider, & M. Schreckenberg, *Pedestrian and Evacuation Dynamics 2008*, 171-182. Springer.

León, J. and March, A. (2016). An urban form response to disaster vulnerability: Improving tsunami evacuation in Iquique, Chile. *Environment and Planning B: Planning and Design,* 43, 5, 826–847.

León, J., & March, A. (2014). Urban morphology as a tool for supporting tsunami rapid resilience: A case study of Talcahuano, Chile. *Habitat International*, 43, 250-262.

León, J., Mokrani, C., Catalán, P., Cienfuegos, R. and Femenías, C. (2018). Examining the role of urban form in supporting rapid and safe tsunami evacuations - A multi-scalar analysis in Viña del Mar, Chile. *Procedia Engineering*, 212, 639-636.

Lindell, M. and Prater, C. (2007). Critical Behavioral Assumptions in Evacuation Time Estimate Analysis for Private Vehicles: Examples from Hurricane Research and Planning. *Urban Planning,* 1, 18, 18-29.

Lindell, M., Lu, J.-c. and Prater, C. (2005). Household Decision Making and Evacuation in Response to Hurricane Lili. *Natural Hazard Review*, 6, 171-179.

Litman, T. (2006). Lessons from Katrina and Rita: What major disasters can teach transportation planners'. *Journal of Transportation Engineering,* 132, 1, 11-18.

Martínez, C., Rojas, O., Jaque, E., Quezada, J., Vásquez, D. and Belmonte, A. (2011). Efectos Territoriales del Tsunami del 27 de Febrero de 2010 en la Costa de la Región del Bio-Bío, Chile. *Revista Geográfica de América Central*, 2, 1-16.

Mas, E., Suppasri, A., Imamura, F. and Koshimura, S. (2012). Agent-Based Simulation of the 2011 Great East Japan Earthquake/Tsunami Evacuation: An Integrated Model of Tsunami Inundation and Evacuation. *Journal of Natural Disaster Science,* 34, 1, 41-57.

Mayring, P. (2010). *Qualitative Inhaltsanalyse Grundlagen und Techniken.* Weinheim: Beltz Verlag.

Miran, S., Ling, C. and Rothfusz, L. (2018). Factors influencing people's decision-making during three consecutive tornado events. *International Journal of Disaster Risk Reduction*, 28, 150-157.

Munich RE, N. (2018, 10 17). Number of relevant natural loss events worldwide 1980-2017. Retrieved 10 17, 2018, from https://natcatservice.munichre.com/events/1?filter=eyJ5ZWFyRnJvbSI6MTk4MCwieWVhclRvIjoyMDE3fQ%3D%3D&type=1.

Municipalidad Talcahuano. (2018). *Gestión de Riesgo - Municipalidad Talcahuano*. Retrieved 11 28, 2018, from http://www.talcahuano.cl/municipio/direcciones/direccion-de-seguridad-publica-y-operaciones/gestion-del-riesgo.

Muñoz, D. (2014). Más de 120.000 personas fueron evacuadas en Arica e Iquique tras sismo. *La Tercera*.

Nakaya, N., Nemoto, H., Yi, C., Sato, A., Shingu, K., Shoji, T., . . . Tomita, H. (2018). Effect of tsunami drill experience on evacuation behavior after the onset of the Great East Japan Earthquake. *International Journal of Disaster Risk Reduction* 28, 206-213.

Naser, M. and Birst. S. C. (2010). Mesoscopic Evacuation Modeling for Small to Medium-Sized Metropolitan Areas. North Dakota State University.

Nobuo, M., Kazuya , Y., Seiki , K., Hiromune , Y. and So , K. (2011). Damage from the Great East Japan Earthquake and Tsunami - A quick report. *Mitigation and Adaptation Strategies for Global Change, 16*, 7, 803-818.

Oh, E. (2010). *Impact analysis of natural disasters on critical infrastructure, associated industries, and communities.* (P. University, Ed.) West Lafayette, USA: ProQuest Dissertations Publishing.

Pan, X., Han, C., Dauber, K. and Law, K. (2007). A Multi-agent Based Framework for the Simulation of Human and Social Behaviors during Emergency Evacuations. *AI & Society,* 22, 2, 113–132.

Pel, A., Bliemer, M. and Hoogendoorn, S. (2012). A review on travel behaviour modelling in dynamic traffic simulation models for evacuations. *Transportation,* 39, 1, 97–123.

Perry, R. (1979). Evacuation Decision-Making in Natural Disasters. *Mass Emergencies*, 4, 25-38.

Perry, R. and Green, M. (1982). The Role of Ethnicity in the Emergency Decision-Making Process. *Sociological Inquiery,* 52, 4, 306-334.

Perry, R. and Lindell, M. (2003). Preparedness for Emergency Response: Guidelines for the Emergency Planning Process. *Disasters,* 27, 4, 336-350.

Quarantelli, E. (1980). *Evacuation Behavior and Problems: Findings and Implications from the Research Literature.* Columbus, USA: The Ohio State University.

Quarantelli, E. (1990). *The warning process and evacuation behavior: the research evidence.* Delaware, USA: University of Delaware Disaster Research Center .

Ramos, L. (2016). Urban Evacuation Tsunamis: Guidelines for Urban Design. *Journal of Engineering and Architecture,* 4, 2, 117-132.

Rinaldi, S., Peerenboom, J., and Kelly, T. (2001). Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies. *IEEE Control Systems Magazine*, 11-25.

Riveros, J. (2014). Automovilistas iquiqueños no dejaban huir a pie. *Las Últimas Noticias.*

Rojas Vilches, O., Sáez Carrillo, K., Martínez Reyes, C. and Jaque Castillo, E. (2014). Efectos socioambientales post-catástrofe en localidades costeras vulnerables afectadas por el tsunami del 27/02/2010 en Chile. *Interciencia - Revista de Ciencia y Tecnología de América*, 39, 6, 383-390.

Shapira, S., Aharonson-Daniel, L. and Bar-Dayan, Y. (2018). Anticipated behavioral response patterns to an earthquake: The role of personal and household characteristics, risk perception, previous experience and preparedness. *International Journal of Disaster Risk Reduction*, 31, 1-8.

Shuto, N. (2005). Tsunamis: Their Coastal effects and Defense Works. Scientific Forum on Tsunami, Its Impact and Recovery, 1-12. Thailand: Asian Institute of Technology.

Smith, S. and Mccarty, C. (2009). Fleeing the Storm(s): An Examination of Evacuation Behavior During Florida's 2004 Hurricane Season. *Demography,* 46, 1, 127-145.

U.S. Geological Survey and U.S. Department of the Interior. (2011). *Report on the 2010 Chilean Earthquake and Tsunami Response.* Virginia.

U.S. Geological Survey, Earthquake Hazards Program. (2010). M 8.8 - offshore Bio-Bio, Chile. Retrieved 11 12, 2018, from https://earthquake.usgs.gov/earthquakes/eventpage/official20100227063411530_30/executive.

Urlainis, A., Shohet, I., Levy, R., Ornai, D. and Vilnay, O. (2014). Damage in critical infrastructure due to natural and man-made extreme events - a critical review. *Procedia Engineering*, 85, 529 – 535.

Vargas, G., Farías, M., Carretier, S., Tassara, A., Baize, S. and Melnick, D. (2011). Coastal uplift and tsunami effects associated to the 2010. *Andean Geology,* 38, 1, 219-238.

Whitehead, J., Edwards, B., Van Willigen , M., Maiolo, J., Wilson, K. and Smith, K. (2000). Heading for higher ground: factors affecting real and hypothetical hurricane evacuation behavior. *Environmental Hazards* 2, 133-142.

Yosritzal, K., Purnawan and Putra, H. (2018). An observation of the walking speed of evacuees during a simulated tsunami evacuation in Padang, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 012090.

Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios

Sebastian Lindner
Chair of Information Management
Martin Luther University, Halle, Germany
sebastian.lindner@wiwi.uni-halle.de

Stefan Sackmann
Chair of Information Management
Martin Luther University, Halle, Germany
stefan.sackmann@wiwi.uni-halle.de

Hans Betke
Chair of Information Management
Martin Luther University, Halle, Germany
hans.betke@wiwi.uni-halle.de

ABSTRACT

Fast and easy communication, e.g. via Twitter or Facebook, encourages self-coordination between spontaneous volunteers in disasters. Unfortunately, this is more and more challenging official disaster management. The need for the directed coordination of spontaneous volunteers triggered researchers to develop effective coordination approaches. However, evaluating and comparing such approaches as well as their exercising are lacking a standardized way to describe repeatable disaster scenarios, e.g. for simulations. Therefore, we present a novel System Entity Structure (SES) for describing disaster scenarios considering the disaster environment, communication infrastructure, disaster management, and population of spontaneous volunteers. The SES is discussed as a promising scheme for including spontaneous volunteers in disaster scenarios on a general level. Its applicability is demonstrated by a Pruned Entity Structure derived from a real disaster scenario. Based on the results, we give an outlook on our subsequent research, the XML-based Spontaneous Volunteer Coordination Scenario Definition Language (SVCSDL).

Keywords

Agent-based Simulation, Spontaneous Volunteers, Spontaneous Volunteer Coordination Scenario Definition Language (SVCSDL), System Entity Structure (SES), Disaster Scenario.

INTRODUCTION

Spontaneous volunteers, i.e. people who spontaneously help in urgent disaster situations and who are not affiliated to official civil protection organizations (Barraket *et al*., 2013; Ludwig *et al*., 2017; Zettl *et al*., 2017), play an important and active role in disaster response (Fernandez, Barbera and Dorp, 2006; Sauer *et al*., 2014; Lindner, Betke and Sackmann, 2017; Ludwig *et al*., 2017). For years, the phenomenon of spontaneous volunteers in major disaster events has moved both the media and research. Modern communication technologies, such as social media, have raised the phenomenon of spontaneous volunteers to a new level (Meissen *et al*., 2017; Reuter and Kaufhold, 2018) that makes an examination of the topic in disaster management indispensable. During the disastrous floods 2013 in Germany, the continuous presence of the disaster in social media led to massive participation of the population to cope with the disaster. While this spontaneous support of the official disaster relief forces was crucial for overcoming the disaster, it also led to various problems: due to incorrect and subjectively designed information some operating sites were overcrowded by volunteers whereas others were dramatically understaffed, and several volunteers exposed themselves to danger through unauthorized actions (Fernandez, 2007; Hofmann, Betke and Sackmann, 2014).

The enormous cooperativeness of spontaneous volunteers, as well as the lack of approaches for their coordination, have triggered a large number of new research projects (German Federal Ministry of Education and Research, 2018b). Several projects, e.g. KUBAS (Rauchecker and Schryen, 2016), AHA (German Federal Ministry of Education and Research, 2018a), REBEKA (Johanniter-Unfall-Hilfe e.V., 2018), ENSURE (Fraunhofer-Institut für Offene Kommunikationssysteme FOKUS, 2018), KOKOS (Project KOKOS, 2018) or K3 (German Federal Ministry of Education and Research, 2018c), explore the improvement of the coordination of spontaneous volunteers by using modern information and communication technologies. Recently developed concepts, demonstrators, and prototypes are confronted with the challenge of scientific evaluation to demonstrate and compare their usability and added value. This may be done in real disasters or field tests, that, however, are usually too expensive, elaborate, and partly impossible to conduct. Since field experiments are not sufficiently realistic, real disasters are too dangerous and both are hardly reproducible, computer simulation is an appropriate approach to test, evaluate, and optimize real-world scenarios and approaches with a minimal effort. Furthermore, simulations enable the disaster staff to perform exercises in using such systems at regular intervals due to the possibility to describe and define reproducible disaster scenarios. Simulating spontaneous volunteers can also facilitate the possibility of forecasting their behaviors in real disaster situations.

Regardless of how such evaluations or exercises are carried out methodically (e.g. field trials, simulations), a reusable, standardized, and ideally formalized description of disaster situations is required. Since such suitable methods do not yet exist, our research goal is to develop a model for the specification of disaster scenarios including spontaneous volunteers as an artifact that is further the basis for the subsequent development of an XML-based Spontaneous Volunteer Coordination Scenario Definition Language (SVCDSL). On the one hand, the model enables an understanding of disaster scenarios with spontaneous volunteers on a conceptual level, e.g. to develop scenarios for field trials. On the other hand, it provides the basis for developing an executable disaster scenario definition language for simulations.

The artifact development is part of a research project following the well-established Design Science Research Process methodology proposed by Peffers et al. (Peffers *et al*., 2007) and covers the third phase – "Design and Development". The whole project aims at the development of a universal spontaneous volunteer simulation application in disaster situations to evaluate and compare spontaneous volunteer coordination approaches as well as to predict the volunteers' behaviors in acute disaster situations. Agent-based simulation has therefore been identified as a proper method to simulate the behavior of spontaneous volunteers in a disaster context. Results of the first two DSRP-phases of this project are described in (Lindner *et al*., 2018; Lindner, Betke and Sackmann, 2017) where a structured literature analysis has been performed and a conceptual model of spontaneous volunteer behavior has been developed. To further enable the comparison and evaluation of spontaneous volunteer coordination approaches using agent-based simulations, it is required to identify all relevant entities as well as to establish reproducible and machine-processable scenarios. Since the development of the language artifact in this paper requires a constant exchange with experts, specialists and end-users and the results have to continuously be evaluated and improved, Action Design Research (ADR) according to Sein et al. (Sein *et al*., 2011) is utilized as a concrete method.

Based on other studies, as a first step, so-called System Entity Structures (SES) are identified and discussed as an adequate approach for our research (Section 2). Accordingly, in Section 3, relevant elements for describing disaster scenarios are identified from the literature. Following the corresponding IEEE guideline for scenario development, in Section 4 the identified elements are categorized and used for developing the aspired artifact. The applicability of the developed SES is demonstrated in Section 5 by using a concrete example of the 2013 flood disaster and transferring the SES into a so-called Pruned Entity Structure (PES). As a final step, the developed SES is discussed and an outlook for defining an open and extensible XML-based language called Spontaneous Volunteer Coordination Scenario Definition Language (SVSDL) is given.

DEVELOPING SCENARIOS WITH SYSTEM ENTITY STRUCTURES

Reproducible, reusable, and executable scenarios provide a sound foundation to evaluate coordination approaches and systems as well as to compare different ones since these scenarios enable the measurement of differences under identical circumstances. The IEEE defines scenarios on the one hand as a description of an exercise that "is part of the session database that configures the units and platforms and places them in specific locations with specific missions" (IEEE, 2011). On the other hand, scenarios are described as "[an] initial set of conditions and timeline of significant events imposed on trainees or systems" (IEEE, 2011). Although the definition and development of scenarios are defined by the IEEE on a general level, a particular method to perform scenario creation is not proposed. Instead, the selection of a proper tool or technique is seen as one explicit step of the scenario development (IEEE, 2011). To determine a suitable method for developing the aspired scenario, a literature review has been performed to identify publications that either have developed simulation scenarios in

general or that have defined scenarios for the coordination of spontaneous volunteers in particular.

For the literature review, the keywords *simulation*, *scenario*, *reproducible*, *spontaneous volunteer*, *coordination*, *scenario language*, *scenario development, agent-based simulation, disaster* and some of their combinations have been searched in various scientific databases, such as WileyOnline, ScienceDirect, SpringerLink etc. as well as in Google Scholar. We have limited our search to publications after 2000 to maintain a certain topicality. In addition, forward and backward searches have been carried out to identify further relevant publications.

The literature review revealed that the development of models for standardization and description of scenarios is addressed in various areas. For example, the Military Scenario Definition Language (MSDL) published by the Simulation Interoperability Standards Organization (SISO) has been established in the military sector (Blais, 2008; Wittman Jr., 2009). Other models exist in the transportation sector where road traffic, particularly driver behavior, was described, e.g. (Adler *et al.*, 2005; Fuchs *et al.*, 2008). Standardized scenarios are also used in health management to train nurses for emergencies (Waxman, 2010; Alinier, 2011). Furthermore, Jafer et al. have developed a language that describes standard scenarios in aviation (Jafer *et al.*, 2016). In addition, there are many contributions dealing with the development of scenarios for multi-agent systems on a general level (Murakami *et al.*, 2003; Nakajima *et al.*, 2006).

The literature review also revealed that several authors research on the question of how scenarios can be developed to better manage disasters and predict their progressions (e.g. (Sun *et al.*, 2015)). However, the proposed models are either very specific (e.g. (Su, Wang and Zhang, 2016; Simões *et al.*, 2011)) and not suitable for standardization or the scenarios rather focus on decision support for emergency forces and aid organizations (e.g. (Drury *et al.*, 2009)) and do not take spontaneous volunteers as valuable resources into consideration. In summary, our literature review revealed that there is no description of disaster scenarios especially focusing on the coordination of spontaneous volunteers yet. This fosters our effort to develop a corresponding Scenario Definition Language for describing and executing such scenarios.

However, the identified work revealed successfully applied tools and techniques for developing scenarios. In particular, the Simulation Scenario Development (SSD) as a method proposed by the IEEE has already been approved, e.g. (Jafer and Durak, 2017). Following the SSD approach, the foundation of any scenario documentation is the identification of entities, their behaviors, and events that need to be represented in the scenario(s) (IEEE, 2011). Since the behavior inevitably results from the simulation environment, we focus on the identification of events and entities. The SSD approach described by the IEEE merely provides steps that are necessary for a successful scenario definition, but, unfortunately, it does not discuss its actual application. For applying the SSD, several researchers in different domains have already successfully used so-called System Entity Structures (SES) as a methodological framework (see, e.g. (Ntaimo *et al.*, 2004; Lee and Zeigler, 2010; You, Chi and Kim, 2013; Schmidt, Durak and Pawletta, 2016; Durak *et al.*, 2017)). SES is using a data model that reflects system-engineering concepts of hierarchical decomposition and specialization (Cheon, Kim and Zeigler, 2008). SES is also based on a limited set of elements (entity, aspect, specialization, and multi-aspect) and axioms that can be introduced as a directed labeled tree (Durak *et al.*, 2017). Since this characteristics allow an automatic creation of XML schemata (Cheon, Kim and Zeigler, 2008), SES is seen as suitable to close the gap between structured scenario definitions proposed by IEEE and a machine-processable language and, thus, it is seen as an appropriate method leading to the aim of our research, namely the desired SVCSDL.

Simulation scenarios can be categorized into three types that need to be developed in the scenario development process, namely operational scenario, conceptual scenario, and executable scenario (Siegfried *et al.*, 2012; Simulation Interoperability Standards Organization, 2015). Accordingly, the operational scenario usually describes the targeted real-world scenario in a textual form providing a broad description of the desired events and elements. For our research, descriptive reports on coordinating spontaneous volunteers have been analyzed to provide basic information on how volunteers were coordinated in real disaster situations. The results of this analysis as well as the required deeper investigation on element details and interrelations are presented in Section 3 leading to the identification of entities and, consequently, to the conceptual scenario, that usually is a formal metamodel representation. As the basis for a formal description of an executable scenario in an XML-Schema that can be processed by simulation applications, all scenario-specific information is subsequently represented as a System Entity Structure (see Section 4).

ELEMENTS FOR DESCRIBING DISASTER SCENARIOS WITH SPONTANEOUS VOLUNTEERS

To develop scenarios, it is important to understand what distinguishes them. According to the IEEE guideline, scenario(s) include "types and numbers of major entities/objects that must be represented within the simulation environment" (IEEE, 2011). Consequently, the IEEE describes scenarios to have various entities being represented within the aimed at environment. As SES has already been applied to define scenarios, we adopt this

method to develop the spontaneous volunteer coordination scenario. In "Modeling & Simulation-Based Data Engineering: Introducing Pragmatics into Ontologies for Net-Centric Information Exchange" Zeigler and Hammonds explain the development of SES and all related elements. In general, SES consists of Entities, Aspects and Specializations. According to Zeigler and Hammonds "Entities represent things that exist in the real world or sometimes in an imagined world. Aspects represent ways of decomposing things into more fine-grained ones. Multi-aspects are aspects for which the components are all of one kind. Specializations represent categories or families of specific forms that a thing can assume" (Zeigler and Hammonds, 2007).

The required authoritative domain information for the scenario development (IEEE, 2011) have been identified and analyzed by literature reviews, preliminary work and expert discussions. In this section, according to the SES development by Zeigler and Hammonds, we will discuss the relevant entities for describing disaster situations and decompose them into specializations and multi-aspects and, if necessary, attach variables to the identified entities.

As basic entities that are discussed in the following in more detail, we identified **Disaster Management** and **Spontaneous Volunteers** inevitably resulting from the targeted domain and research goal. According to the IEEE guideline, the **Environment** must be taken into consideration and, thus, is a basic entity that represents a superset of the scenario components. As experiences show, communication has a significant influence on the self-coordination of spontaneous volunteers as well as on the possibilities for official disaster management to coordinate them according to the official needs. Sackmann et al. even see communication as a central design object for the coordination of supporting activities (Sackmann *et al*., 2018). Thus, as forth entity, **Communication Infrastructure** is defined as a basic entity for our scenario description as well. Furthermore, the IEEE guideline suggests modeling scenario triggers and stop conditions. As a starting point, these are defined according to the typical phases of disaster scenarios (Thieken *et al*., 2007): the scenario gets triggered by the disaster event and the beginning of the disaster response phase or its simulation. The stop of the scenario is given over to the scenario modeler since it depends on the particular goal.

Environment (Basis Entity #1)

According to the IEEE guideline, the environment is a superset of the scenario components comprising aspects, e.g. geographical regions, natural environment conditions, initial and termination conditions. This entity with its aspects defines the general behavior of entities and, consequently, the simulation of their behavior.

Inherently important for any disaster scenario and its simulation is the definition of **geographical areas**. There exist several concepts for defining areas, e.g. center point and radius (Nelson, Iii and Kravets, 2007) or polygonal pathways (Wagner and Agrawal, 2014). There might be good reasons for describing geographical regions in a very detailed manner. However, as a starting point for our scenario description, we decided to use a simple concept of overlapping circles that are defined by their center (longitude/latitude) and radius. Extending or replacing this simple concept is easy to realize without changing the general result of our research. These geographical areas are represented in our SES as a Multi-aspect as there can be several areas or locations within the environment and accordingly within the scenario. The definition of the geographical areas at the beginning of the scenarios enables the re-utilization of these regions in other entities within the SES.

Our literature review revealed **weather** to be one main aspect in the disaster context (e.g. (Geißler, 2014; Kircher, 2014)). It is not only relevant to the disaster itself but also for the willingness of volunteers to help (Geißler, 2014; Kircher, 2014). Thus, the weather was chosen to be represented within the SES. Reports and publications on past disasters proposing the weather as an influencing factor usually describe weather with attributes like "nice", "warm", "bad", "rainy" etc. (Geißler, 2014; Rauchecker and Schryen, 2018) However, since such terms are rather subjective and vague, we propose a more general type of description in terms like precipitation, rain intensity, temperature, humidity, etc. as variables in our SES. These variables can subsequently be interpreted and used to simulate the influence of weather on, e.g. the motivation of spontaneous volunteers to help. In the SES, we represent the weather as a Multi-aspect as, in combination with the geographical areas, weather can be defined locally and may be different within one scenario.

Communication Infrastructure (Basis Entity #2)

Recent disasters have shown that communication (between spontaneous volunteers themselves as well as between volunteers and official disaster management) and limited accessibility has played a crucial role in the (self-)coordination of spontaneous volunteers (Reuter and Kaufhold, 2018). Communication infrastructure and their availability in a disaster situation determine how information be disseminated and, thus, have to be described within the scenario definitions. Literature and experiences show that communication is at least determined by its technical as well as its organizational realization (see, e.g. (Asplund, Nadjm-Tehrani and Sigholm, 2009; Reuter and Kaufhold, 2018)). Thus, we defined these two dimensions as relevant aspects of our

scenario description.

From a technical perspective (**technologies**), communication infrastructure can differ with respect to communication channels and, thus, with respect to communication content. For example, SMS are limited to text-only content and require at least a GSM network, whereas mobile applications or social networks are not necessarily limited to a number of characters or text/media but require different infrastructures such as the Internet via WIFI, LTE, or HSDPA. Since the availability or access to communication technology is usually confined (e.g. not all people use all communication channels in parallel, limited capacity on the side of network provider, blackout), the description of a disaster scenario should necessarily enable the definition of capacities for specific areas. Thus, we defined communication technologies as a Multi-aspect of communication infrastructure as one scenario can have several technologies in different areas with different capacities.

From an organizational perspective (**communication types**), a first relevant characteristic of communication is the type of communication **participants**. Since self-coordination between volunteers as well as directed coordination of volunteers by official disaster management is in the focus of our research, communication participants include at least the official disaster management (**DM**) and the spontaneous volunteers (**SV**). Since both parties can be sender as well as the receiver of information, this is seen as one main aspect for describing communication infrastructure. A second main aspect is whether the **relationship** between sender and receiver is a one-to-one (**one2one**) or a one-to-many (**one2many**) relation. The possibility to describe these relations allows, together with the categorization of the communication participants, to define general possibilities for uni- or bidirectional communication. Scenarios can, thus, be limited to, e.g. the communication between spontaneous volunteers among themselves in a broadcasting manner (one2many) and, thus, influence their behavior and the kind of information that may be disseminated. However, also the technological perspective may play a role in how and which information can be disseminated, why we see technologies as a third influencing and limiting aspect in the communication type. As we assume that technologies indispensably be linked with the relationship and participants, we represent both, relationship and participants as Specializations that necessitate a selection of each. E.g. one kind of participant (e.g. SV2SV), can have one relationship (e.g. one2many), that can be realized upon a selection of technologies. This general description allows remaining open for current (and also future) communication technologies.

Disaster Management (Basis Entity #3)

Disaster management is responsible for organizing response activities during a disaster in order to minimize its impact. Disasters are tackled at so-called **operating sites** by disaster management, where official disaster relief forces work—sometimes supported by spontaneous volunteers—to mitigate disaster scales. Typically, disaster response and mitigation are conducted based on a command and control structure of different levels whereas the disaster management is on a strategical level, e.g. in the form of crisis committees. Operating sites are on a tactical or operational level. Since disaster management is usually organized from an official site (e.g., government) and usually not supported by spontaneous volunteers, the disaster management entity in our approach is focused on the description of operating sites. Operating sites are commonly the only physical contact points between spontaneous volunteers and official disaster relief forces. However, a subsequent extension of the model may include the integration of other crisis units and/or on-site emergency personnel in the future.

Following literature and official organization rules, operating sites are mainly characterized by its location resp. area (**geographicArea**), its required tasks and durations, and required resp. available resources. Depending on the scenario, there can be different operating sites, while each operating site can require different **tasks** to be fulfilled for completion (Rauchecker and Schryen, 2018). For example, common tasks in a flooding scenario may be sandbag filling, carrying sandbags, and so on at different locations along a river. However, the tasks that may be required on operating sites can differ and, thus, have to be considered within the scenario. Since our research is focused on the use of spontaneous volunteers as a valuable resource on operating sites, the coordination of operating sites is restricted to tasks that could be supported or executed by spontaneous volunteers. Therefore, we modeled the operating sites consisting of tasks and its locations as well as by defining the required number of volunteers working at a specific task for completing it effectively. Also, we identified the estimated duration of the specific task as an important variable as it influences the number of required volunteers per time unit and further has an effect on volunteers' decision to help if it is known.

Spontaneous Volunteers (Basis Entity #4)

For describing a disaster scenario, it would not be helpful to define each spontaneous volunteer and his/her decisions and behaviors individually. This would lead to a deterministic scenario and would not fulfill the requirements for using the described scenario for the evaluation of coordination systems or performing disaster

exercises. Consequently, spontaneous volunteers are described in the form of populations with probability distributions of relevant variables and entities.

To describe characteristics of individual spontaneous volunteers and their motivation to help during a disaster, the state-of-the-art is extensively discussed in (Lindner, Betke and Sackmann, 2017) providing a solid basis for describing spontaneous volunteers in disaster scenarios. Accordingly, the age, experience, concernment, etc. were exemplarily adopted into the SES as variables to describing the **general** characteristics of the population. A comprehensive list of all relevant variables is given in (Lindner, Betke and Sackmann, 2017). To assign these attributes, the required distributions can either be chosen at will or they can be derived from (demographic) data of the respective location. Since the related literature still is in an early research phase and its behavior impacting attributes have not yet fully been proven, we propose these variables to be extended in future versions. Also, the population size of potential volunteers might differ between different areas, like there are usually massive differences between rural and urban areas. To describe these location-dependent differences in disaster scenarios, we propose **geographic areas** to be an aspect of each population, particularly being an aspect of the general entity. The location-dependent modeling of populations may lead to the representation of many populations within the scenario.

In addition to these general characteristics, the description of spontaneous volunteers should be extended by their communication abilities. As mentioned, when discussing the communication infrastructure, the use of communication devices and, thus, **technologies** vary from person to person. Consequently, the availability of communication technologies is defined as an additional aspect for spontaneous volunteer populations that should be represented in disaster scenarios. For instance, the distribution of smartphone users, users of social media, etc. would be reasonable, if these infrastructures are modeled within the scenario in the communication infrastructures. Therefore, the distribution per each technology used in the scenario must be specified to affect the volunteer's behavior.

We have further identified variables and entities that are related to the **operations** spontaneous volunteers can have. One main characteristic of volunteers is their willingness and ability to perform specific tasks. Since not everybody is able to carry heavy sandbags or to take care of shocked people, this restriction has to be part of any scenario definition. The description of scenario-specific **tasks** has already been discussed in the context of disaster management, thus, to represent these tasks within the volunteer populations, we propose a distribution of all tasks within a scenario. Another behavior-impacting aspect of volunteers is external restrictions like country-specific legal requirements or regulations. Such regulations may limit the working time of spontaneous volunteers to a few hours per day. E.g., German law restricts the working time to 8 hours per day.[1] Also, physical abilities and other commitments may affect the working time. Furthermore, individual working duration preferences, i.e. for how many days a volunteer will help, have to be modeled. Thus, for describing the operation within the SES, we propose the variables "workTimeDistribution", "workDurationDistribution" as well as the aspect "tasks".

MODELING SCENARIO ELEMENTS WITH SYSTEM ENTITY STRUCTURE

The entities, (multi-)aspects, specifications, and variables defined and described in the previous section represent the static dimension of the aspired scenario description. To complete the SES according to the IEEE specification, a dynamic dimension is required, namely the time-dependent progression of simulation scenarios (IEEE, 2011). To describe the dynamics of a disaster scenario, the scenario itself, as well as the variables of the entities, have to be changeable during the scenario. The IEEE proposes time-related events that trigger a change in the parameters at the respective point in time and are accordingly interpreted by the simulation software. Since events can affect all identified SES elements, they are defined as a common characteristic at the top of the SES hierarchy. Depending on the dynamics and level of detail, a simulation scenario can consist of any number of events. We suggest the use of the actual time (time and date) for executing a disaster scenario, since time might also influence the behavior of the spontaneous volunteers (see (Lindner, Betke and Sackmann, 2017)). Consequently, we propose datetime as a variable of the event. Nevertheless, faster processing of the events in the scenarios can be facilitated by the acceleration of simulation experiments. As result, the identified and discussed mandatory elements for describing and executing disaster scenarios with taking spontaneous volunteers into consideration are depicted as an SES in Figure 1.

[1] section 3 German Hours of Work Act (ArbZG)

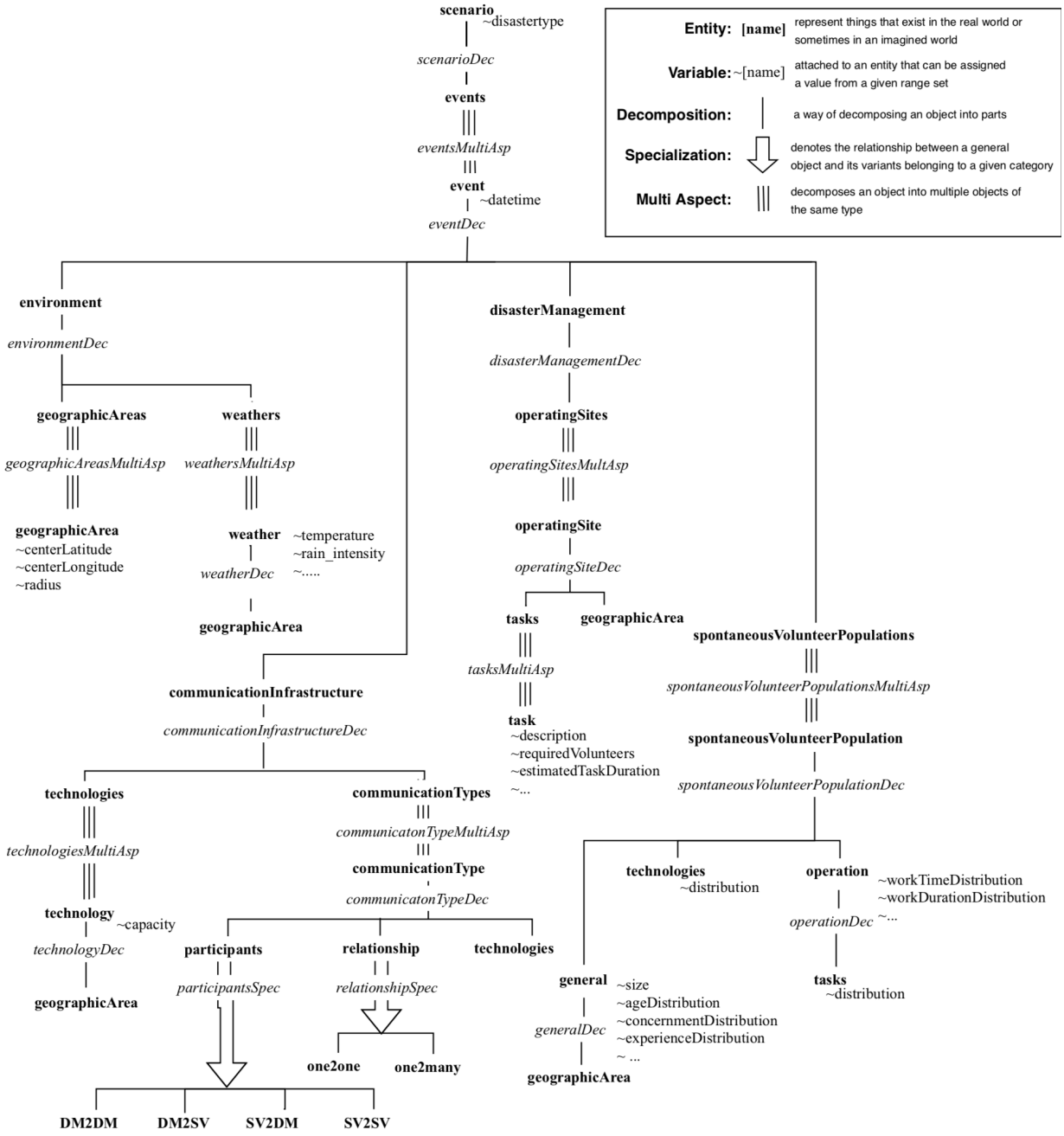


Figure 1. System Entity Structure for Disaster Scenarios

EXEMPLARY PRUNED ENTITY STRUCTURE ON 2013 FLOOD SCENARIO

To demonstrate the applicability of the proposed SES for disaster scenarios, an exemplary and simplified real-world scenario is described. Subsequently, this scenario is transformed into a so-called Pruned Entity Structure (PES) by resolving the elements of the scenario to the aspects, multi-aspects, specializations and by assigning values to the variables resulting in a selection-free tree (Durak *et al*., 2017).

The scenario has been developed in cooperation with the responsible leader of the local disaster management authority and represents an excerpt of the flood that took place in 2013 in Halle (Saale), Saxony-Anhalt, Germany. Firstly, the scenario is described in a textual form (translated from German) and secondly, it is used to derive the PES model. All scenario-relevant elements, i.e. elements that are represented in the SES, are marked bold to better understand the development of the PES.

"The **flooding** in **Halle (Saale),** became worse on the **4th of June**. Due to the impending flooding of downtown, further sand deliveries were transported to the **sandbag filling station** on the **market place** at around **2 pm**. Due to the **midsummer weather**, there were more volunteers on site than the **100 helpers actually needed**, which

challenged our personnel with additional organizational effort. Probably the central location and the proximity to the university played a role in the overcrowding market place but also the dissemination of subjective information by the local citizens via **social media** such as Facebook. In contrast, the crisis management team focused on the dissemination of information via traditional media, such as **radio**. Nevertheless, we were thankful for the numerous volunteers who helped by **filling the sandbags** at the marketplace for **more than 18 hours**."

This scenario is just a very short and basic example for pruning the SES for the disaster type: **flooding** and the datetime: **06/04/13 02:00 pm**. Since the textual scenario description is free in its structure and not complete at all, some variable assignments have to be interpreted resp. assumed. The **city** and the **market place** have been defined as geographical areas according to their center coordinates and an adequate radius. Furthermore, **midsummer-weather** has been assumed for the whole city and resolved in a temperature of 29°C and rain intensity of 0 mm/h.

As available (or relevant) communication technologies, **social media** and **radio** have been defined for the whole city. The technical capacity for both technologies is set to 100% since there haven't been reports of lacking communication availabilities during the disaster event. Since **social media** has only been used by the volunteers among themselves to communicate one-to-many, it has been interpreted as communicationType. Since official disaster management has only used **radio** for informing the volunteers, it has been defined in the same manner.

The **sandbag filling station** on the **market place** has been defined as one operating site with only one task, namely **sandbag filling**. The variables have been set to 100 volunteers needed and 18 hours estimated duration.

To define the population of volunteers, some information were not given in the textual description. E.g., we have assumed one population representing the number of inhabitants of **Halle** in 2013 according to the official statistics. The technology distributions have been chosen in line with official statistics for the percentage of people who daily use radio or social networks in Europe (European Commission, 2017).

Since we have no information on how long and how many days people have worked, we have assumed triangular distributions for workingTime (min: 2 hours, peak: 4 hours, max: 8 hours) and workingDuration (min: 1 day, peak: 3 days, max: 7 days) that seem logical to us.

Furthermore, we have assumed that only half of the population is able or willing to do heavy work. Consequently, the distribution for the task **sandbag filling** has been set to 50%. The resulting PES for the representation of the textual scenario description including all identified and interpreted information is depicted in Figure 2.

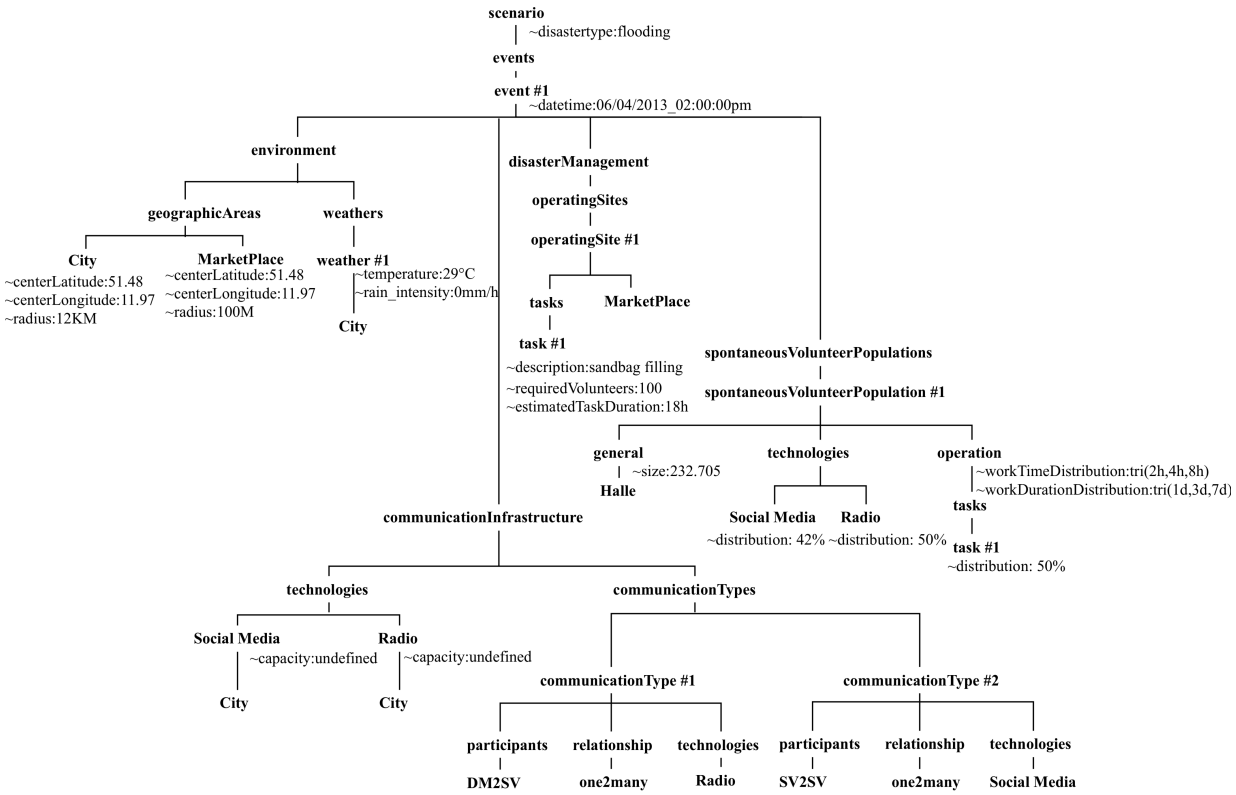


Figure 2. Pruned Entity Structure for Example Scenario

DISCUSSION AND OUTLOOK

The increasing relevance of spontaneous volunteers has led to the development of numerous research approaches aiming at their improved coordination. However, these approaches require on the one hand evaluations to test their added value and, on the other hand, a comparison to choose the approach that matches the requirements of official disaster management to transfer these approaches into practice. Computer simulations, particularly agent-based simulations, seem promising to simulate human behaviors in a disaster context and, thus, to enable evaluations and comparisons of coordination approaches. Nevertheless, agent-based simulations require reproducible disaster scenarios to compare the effects of different coordination approaches. To perform reproducible simulations in the context of spontaneous volunteer coordination, as a first step, scenarios and their related entities have to be analyzed. A second step is to provide these scenario insights as a machine-processable format to be used within the simulation.

The SES model proposed in this paper is a fundamental step for developing a Standard Scenario Definition Language for the coordination of spontaneous volunteers that can be processed within a simulation. In the presented initial version, the focus is restricted to coordination scenarios particularly for simulation experiments and, thus, only contains elements for this purpose. Following an Action Design Research approach (Sein *et al.*, 2011), the SES will be further developed and supplemented in several iteration steps in the future resulting in the SVCSDL. This is necessary, since depending on the purpose, the model may still lack information or higher level of details that may be required by other researchers. Although the SES model contains all basic entities that have been identified in our literature search and interviews addressing the coordination of spontaneous volunteers, an extensive and structured literature review (e.g. following the methodology proposed in (vom Brocke *et al.*, 2009)) is expected to bring further results. Thus, a structured literature review may supplement the proposed model and is part of our future research.

Although the SES was mainly developed for simulations, it might also be valuable for field trials in the spontaneous volunteer coordination context or even as a basis for digital volunteering scenarios as it gives insights and an understanding of what impacts and influences spontaneous volunteer scenarios. Consequently, the proposed SES model contributes to disaster research as it conceptualizes information that relate to scenarios with spontaneous volunteers.

Even though the general goal is to enable the evaluation and comparison of spontaneous volunteer coordination approaches promoted by the scenarios, we have not yet proposed and evaluated adequate measures for evaluating or comparing different coordination approaches. Since this is required for the evaluation of coordination approaches and systems, simulations, exercises, and experiments, it is one focus of our generic research project and an open research topic for the future.

Last but not least, the proposed SES model is the basis to develop an XML-based scenario language that may lead to the implementation and exchangeability of scenarios in simulation software. By defining an extensive standard language based on the SES, research on spontaneous volunteers in disaster situations, as well as the evaluation and comparison of different coordination approaches, will be supported and promoted. Thus, after completing the SES, the next step will be the language definition as a practical research question.

ACKNOWLEDGMENTS

This research has been funded by the Federal Ministry of Education and Research of Germany in the framework of KUBAS (project number 13N13939).

REFERENCES

Adler, J. L., Satapathy, G., Manikonda, V., Bowles, B., and Blue, V. J. (2005) A multi-agent approach to cooperative traffic management and route guidance, *Transportation Research Part B: Methodological*, 39, 4, 297–318.

Alinier, G. (2011) Developing high-fidelity health care simulation scenarios: A guide for educators and professionals, *Simulation and Gaming*, 42,1, 9–26.

Asplund, M., Nadjm-Tehrani, S. and Sigholm, J. (2009) Emerging information infrastructures: Cooperation in disasters, *Lecture Notes in Computer Science*, 5508 LNCS, 2, 258–270.

Barraket, J., Keast, R., Newton, C. J., Walters, K., and James, E. (2013) Spontaneous Volunteering During Natural Disasters, *The Australian Centre for Philanthropy and Nonprofit Studies*, ACPNS61, 1–58.

Blais, C. (2008) Military Scenario Definition Language (MSDL): How Broadly Can It Be Applied?, *Proceedings of the Spring 2008 Simulation Interoperability Workshop,* Providence, Rhode Island, USA.

Vom Brocke, J., Simons, A., Niehaves, B., Riemer, K., Plattfaut, R., and Cleven, A. (2009) Reconstructing the Giant: On the Importance of Rigour in Documenting the Literature Search Process, *17th European Conference on Information Systems*, 2206–2217, Verona, Italy.

Cheon, S., Kim, D. and Zeigler, B. P. (2008) System Entity Structure for XML meta data modeling; Application to the US climate normals, *SEDE,* 216–221, Los Angeles, California, USA.

Drury, J. L., Pfaff, M., More, L., and Klein, G. L. (2009) A principled method of scenario design for testing emergency response decision-making, *Proceedings of the 6th ISCRAM Conference,* Göteborg, Sweden.

Durak, U., Pruter, I., Gerlach, T., Jafer, S., Pawletta, T., and Hartmann, S. (2017) Using System Entity Structures to Model the Elements of a Scenario in a Research Flight Simulator, *AIAA Modeling and Simulation Technologies Conference*, p. 1076, Grapevine, Texas, USA.

European Commission (2017) Media use in the European Union. *Standard Eurobarometer* 88, Report.

Fernandez, L. S. (2007) Volunteer Management System Design and Analysis for Disaster Response and Recovery, *The George Washington University,* Dissertation.

Fernandez, L. S., Barbera, J. a and Dorp, J. R. Van (2006) Strategies for Managing Volunteers during Incident Response : A Systems Approach, *Institutional Archive of the Naval Postgraduate School*, 10, 3, 1–15.

Fraunhofer-Institut für Offene Kommunikationssysteme FOKUS (2018) ENSURE Projekt, *https://www.ensure-project.de/, [Accessed 11 Nov. 2018].*

Fuchs, S., Rass, S., Lamprecht, B., and Kyamakya, K.. (2008) A model for ontology-based scene description for context-aware driver assistance systems, *Proceedings of the 1st international conference on Ambient media and systems*, p. 5, Grapevine, Texas, USA.

Geißler, S. (2014) Motivations of "spontaneous" assistance in the event of a crisis or disaster using the flood events in Magdeburg 2013 as an example (in German: Motivationen „ spontaner “ Hilfeleistungen im Krisen- und Katastrophenfall am Beispiel der Flutereignisse in Magdeburg 2013), *Hochschule für Wirtschaft und Recht Berlin,* Master Thesis.

German Federal Ministry of Education and Research (2018a) AHA: Automated volunteer offering for major incidents (in German: AHA: Automatisiertes Helferangebot bei Großschadensereignissen), *https://www.sifo.de/de/aha-automatisiertes-helferangebot-bei-grossschadensereignissen-2139.html, [Accessed 11 Nov. 2018].*

German Federal Ministry of Education and Research (2018b) Projects approved under the 'Increasing resilience in crisis and disaster situations' call for proposals (in German: Bewilligte Projekte aus der Bekanntmachung ‘Erhöhung der Resilienz im Krisen- und Katastrophenfall’), *https://www.sifo.de/de/bewilligte-projekte-aus-der-bekanntmachung-erhoehung-der-resilienz-im-krisen-und-1936.html*, *[Accessed 11 Nov. 2018].*

German Federal Ministry of Education and Research (2018c) Information and communication concepts for crisis and disaster situations (K3) (in German: Informations- und Kommunikationskonzepte für den Krisen- und Katastrophenfall (K3)), *https://www.sifo.de/files/Projektumriss_K3.pdf*, *[Accessed 11 Nov. 2018].*

Hofmann, M., Betke, H. and Sackmann, S. (2014) Hands2Help – An App-based Concept for Coordination of Disaster Response Volunteers, *I-Com*, 13, 1, 36–45.

IEEE (2011) IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP), *IEEE Std 1730-2010*, 1–79.

Jafer, S., Chhaya, B., Durak, U., and Gerlach, T. (2016) Formal scenario definition language for aviation: Aircraft landing case study, *AIAA Modeling and Simulation Technologies Conference,* p. 3521, Washington, DC, USA.

Jafer, S. and Durak, U. (2017) Tackling the complexity of simulation scenario development in aviation, *Proceedings of the Symposium on Modeling and Simulation of Complexity in Intelligent, Adaptive and Autonomous Systems,* p. 4, Virginia Beach, VA, USA.

Johanniter-Unfall-Hilfe e.V. (2018) REBEKA, *http://www.rebeka-projekt.de/, [Accessed 11 Nov. 2018].*

Kircher, F. (2014) Spontaneous volunteers in disaster management - the view of authorities and organisations with security tasks (in German: Ungebundene Helfer im Katastrophenschutz - Die Sicht der Behörden und Organisationen mit Sicherheitsaufgaben), *BRANDSchutz – Deutsche Feuerwehr-Zeitung*, 593–597.

Lee, H. and Zeigler, B. P. (2010) System Entity Structure Ontological Data Fusion Process Integrated with C2 Systems, *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, 7, 4, 206–225.

Lindner, S., Betke, H. and Sackmann, S. (2017) Attributes for Simulating Spontaneous On-Site Volunteers, *Proceedings of the 14th ISCRAM Conference*, 846–856, Albi, France.

Lindner, S., Kuehnel, S., Betke, H., & Sackmann, S. (2018) Simulating Spontaneous Volunteers-A Conceptual Model. *Proceedings of the 15th ISCRAM Conference*, 159-169, Rochester, New York, USA.

Ludwig, T., Kotthaus, C., Reuter, C., van Dongen, S., and Pipek, V. (2017) Situated crowdsourcing during disasters: Managing the tasks of spontaneous volunteers through public displays, *International Journal of Human Computer Studies*, 102, 103–121.

Meissen, U., Fuchs-Kittowski, F., Jendreck, M., Pfennigschmidt, S., Hardt, M., and Voisard, A. (2017) A general system architecture and design for the coordination of volunteers for agile disaster response, *Proceedings of the 14th ISCRAM Conference*, 890–900, Albi, France.

Murakami, Y., Ishida, T., Kawasoe, T., and Hishiyama, R. (2003) Scenario description for multi-agent simulation, *Proceedings of the second international joint conference on Autonomous agents and multiagent systems,* 369-376, New York, New York, USA.

Nakajima, Y., Shiina, H., Yamane, S., Yamaki, H., and Ishida, T. (2006) Caribbean/Q: A massively multi-agent platform with scenario description language, *2nd International Conference on Semantics Knowledge and Grid*, p. 26, Guilin, China.

Nelson, S. C., Iii, A. F. H. and Kravets, R. (2007) Event–driven , Role–based Mobility in Disaster Recovery Networks, *Proceedings of the second ACM workshop on Challenged networks*, 27-34, New York, New York, USA.

Ntaimo, L., Zeigler, B. P., Vasconcelos, M. J., and Khargharia, B. (2004) Forest Fire Spread and Suppression in DEVS, *Simulation*, 80, 1, 479–500.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007) A Design Science Research Methodology for Information Systems Research, *Journal of Management Information Systems*, 24, 3, 45–77.

Project KOKOS (2018) KOKOS - Supporting cooperation with volunteers in complex emergency situations (in German: KOKOS - Unterstützung der Kooperation mit freiwilligen Helfern in komplexen Einsatzlagen), *https://kokos.wineme.fb5.uni-siegen.de/projekt/, [Accessed 11 Nov. 2018].*

Rauchecker, G. and Schryen, G. (2016) Project KUBAS: Coordination of unbound on-site volunteers (in German: Projekt KUBAS: Koordination ungebundener Vor-Ort-Helfer), *Im Einsatz*, 23, 252–254.

Rauchecker, G. and Schryen, G. (2018) Decision Support for the Optimal Coordination of Spontaneous Volunteers in Disaster Relief, *Proceedings of the 15th ISCRAM Conference,* Rochester, New York, USA.

Reuter, C. and Kaufhold, M. A. (2018) Fifteen years of social media in emergencies: A retrospective review and future directions for crisis Informatics, *Journal of Contingencies and Crisis Management*, 26, 1, 41–57.

Sackmann, S., Lindner, S., Gerstmann, S., and Betke, H. (2018) Involvement of unbound helpers in the management of loss events (in German: Einbindung ungebundener Helfer in die Bewältigung von Schadensereignissen), in: Reuter C. (eds) *Sicherheitskritische Mensch-Computer-Interaktion*, 529–549, Springer Vieweg, Wiesbaden.

Sauer, L. M., Catlett, C., Tosatto, R., and Kirsch, T. D. (2014) The utility of and risks associated with the use of spontaneous volunteers in disaster response: A survey, *Disaster Medicine and Public Health Preparedness*, 8, 1, 65–69.

Schmidt, A., Durak, U. and Pawletta, T. (2016) Model-based testing methodology using system entity structures for MATLAB/Simulink models, *Simulation*, 92, 8, 729–746.

Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., and Lindgren, R. (2011) Action Design Research, *MIS Quarterly*, 35, 1, 37-56.

Siegfried, R., Laux, A., Rother, M., Steinkamp, D., Herrmann, G., Lüthi, J., and Hahn, M. (2012) Scenarios in military (distributed) simulation environments, *SISO 2012 Spring Simulation Interoperability Workshop,* Orlando, Florida, USA.

Simões, André & Rodrigues, Armanda & Pires, Patrícia and Sá, Luís. (2011) Evaluating Emergency Scenarios using Historic Data: Flood Management, *Proceedings of the 8th ISCRAM Conference,* Lisbon, Portugal.

Simulation Interoperability Standards Organization (2015) Standard for Guidance, Rationale, and Interoperability Modalities for the Real-time Platform Reference Federation Object Model, 2.

Su, B., Wang, Z. and Zhang, N. (2016) Urban pluvial flood risk assessment based on scenario simulation, *Proceedings of the 13th ISCRAM Conference,* Rio de Janeiro, Brazil.

Sun, C., Zhang, F., Zhong, S., and Huang, Q. (2015) Expression and Deduction of emergency scenario based on scenario element model, *Proceedings of the 12th ISCRAM Conference,* Kristiansand, Norway.

Thieken, A. H., Kreibich, H., Müller, M., and Merz, B. (2007) Coping with floods: Preparedness, response and recovery of flood-affected residents in Germany in 2002, *Hydrological Sciences Journal*, 52, 5, 1016–1037.

Wagner, N. and Agrawal, V. (2014) An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster, *Expert Systems with Applications*, 41, 6, 2807–2815.

Waxman, K. T. (2010) The Development of Evidence-Based Clinical Simulation Scenarios: Guidelines for Nurse Educators, *Journal of Nursing Education*, 49, 1, 29–35.

Wittman Jr., R. L. (2009) Defining a standard: the Military Scenario Definition Language version 1.0 standard, *Proceedings of the 2009 Spring Simulation Multiconference, San Diego, California, USA*.

You, Y. J., Chi, S. Do and Kim, J. I. (2013) HEAP-based defense modeling and simulation methodology, *IEICE Transactions on Information and Systems*, 3, 655–662.

Zeigler, B. P. and Hammonds, P. E. (2007) Modeling & Simulation-Based Data Engineering: Introducing Pragmatics into Ontologies for Net-Centric Information Exchange, Academic Press, Inc. Orlando, FL, US.

Zettl, V., Ludwig, T., Kotthaus, C., & Skudelny, S. (2017) Embedding unaffiliated volunteers in crisis management systems: Deploying and supporting the concept of intermediary organizations. *Proceedings of the 14th ISCRAM Conference*, 421–431, Albi, France.

Applying Generic AcciMap to a DDOS Attack on a Western-European Telecom Operator

Hans C.A. Wienen
University of Twente
h.c.a.wienen@utwente.nl

Faiza A. Bukhsh
University of Twente
f.a.bukhsh@utwente.nl

Eelco Vriezekolk
Radiocommunications Agency Netherlands
eelco.vriezekolk@agentschaptelecom.nl

Roel J. Wieringa
University of Twente
r.j.wieringa@utwente.nl

ABSTRACT

After a large incident on a telecommunications network, the operator typically executes an incident analysis to prevent future incidents. Research suggests that these analyses are done ad hoc, without a structured approach. In this paper, we conduct an investigation of a large incident according to the AcciMap method. We find that this method can be applied to telecommunications networks with a few small changes; we find that such a structured approach yields many more actionable recommendations than a more focused approach and we find that both the onset of an incident and the resolution phase merit their own analysis. We also find that such an analysis costs a lot of effort and we propose a more efficient approach to using this method. An unexpected outcome was that AcciMap may also be very useful for analyzing crisis organizations.

Keywords

Telecommunications, AcciMap, accident analysis, incident analysis

INTRODUCTION

Telecommunications networks are part of vital and critical infrastructure that needs to be in place for society to run smoothly. Unavailability of telecommunications services can lead to unreachability of emergency services, severe traffic jams and impossibility to inform the populace. In order to make telecommunications networks more robust, we have started the LINC project with the Dutch telecom regulator. Purpose is to analyze incidents on these networks in order to learn from those incidents and share those lessons with the practitioners. These lessons may result in better risk management: impact and probability of risks may be better assessed as result of the lessons and the insights gained may result in better mitigation.

Previously, we conducted a literature review of Accident Analysis Models and Methods (Wienen *et al.* 2019). We identified three families of accident analysis methods and we also identified the methods that had seen the most scrutiny from academia. In this paper, we take the most discussed methods in academia and apply them to a real-life telecommunications incident that severely hindered the email and interactive TV services of the provider.

Please note, that in contrast to the practice in other industries, Telecommunications use the term *incident* as opposed to *accident*. In this paper, we follow this practice and hence with "incident" we mean an undesired and unplanned event that results in a loss, damage or injury.

This paper is organized as follows: first, we will share some theoretical background regarding incident analysis methods; then we pose our research questions. We will describe the research design and then the incident itself, after which we will describe the execution of the research. We then report our results, which we will then discuss and finally we will draw some conclusions, while answering our research questions.

Theoretical Background

Accident Analysis Methods can be divided into three families: sequential, epidemiological and systemic. They differ on the extent in which the socio-technical context and control loops and feedback mechanisms are addressed. As mentioned in (Wienen *et al.* 2019), the families can be described as follows. Note that we talk about incidents where in other domains the term "accident" would be used.:

Sequential incident models describe the accident as the end point of a sequence of causes.

Epidemiological models describe the incident as the product of the interaction among a set of entities and actors, some of which may be visible, and others invisible. In effect, it is a sequence of causes that are inhibited or enabled by environmental factors that also have a place in the model. This model is similar to models of how diseases develop, hence the name. A key factor in epidemiological types of analysis is the description of latent factors that contribute to the development of an unsafe act into an incident.

Systemic incident models describe the incident as the result of the interaction within a tightly coupled system and between the system and its context. Feedback loops may play an important role in these models.

We have applied both FTA (Fault Tree Analysis), the most discussed sequential method as measured in our previous research (Wienen *et al.* 2019), and AcciMap, the most discussed epidemiological method as measured in the same research. However, this paper focusses mainly on the application of AcciMap.

Research question

The telecommunications community does not have a standardized incident analysis model and method, making it hard for authorities to compare incidents and to draw lessons from those incidents. One of the goals of the LINC project is to find or create an incident analysis model and method that can be used to draw lessons from those incidents that can then be shared with the telecommunications operators. Furthermore, in reading existing incident reports, the majority of methods used was of a sequential nature – even though no real formal methods were used. This leads us to ask the following research questions:

1. Do epidemiological methods add more value to the incident analysis in Telecommunications services?
2. Is the Generic AcciMap method a viable method for analyzing Telecommunications incidents?

Research Design

In order to compare the two results, we have co-operated with two Western-European Telecommunications operators. The operators have each selected an interesting case and have provided access to sensitive information. They also provided employees who were involved with the incidents to participate in our incident analysis workshops. This article reports the results of one of the two cases: a DDOS attack.

One researcher conducted the workshops, using Branford's approach (Branford *et al.* 2009) to AcciMap, the *Generic AcciMap Approach*. The other created an FTA according to the definition in the Fault Tree Handbook (Vesely *et al.* 1981). As the incident analysis reveals sensitive information about the company involved, the details of the research have to remain confidential. The company will be called Alpha in the remainder of this article.

Short description of the Incident

According to an internal report drawn up by Alpha as part of the post mortem of the incident,

> *A distributed denial of service attack was staged against Alpha's DNS servers, using several different attacks (DNS reflection, UDP flooding, ICMP flooding). This attack caused Alpha's firewalls to collapse. As a consequence, all services behind the firewall were impacted and the customers experienced outage on DNS, mail, internet and telephony (VoIP). The attack took place in 4 waves which eventually were stopped by applying ACLs, bypassing the firewalls for DNS resolution and redirecting traffic [...] to take advantage of the [...] scrubber.*

In other words: due to an overload of requests, Alpha's firewall collapsed. This caused outage of several services for customers. To resolve the incident, the company had to redirect traffic outside their own network and to clean the traffic to their network from malicious requests.

This description implies two stages to the incident: the stage in which the incident develops and causes its harm (the *onset*) and the stage during which Alpha worked hard to resolve the incident (the *resolution*). Both stages have their own characteristics and we decided during the analysis to treat them separately, resulting in individual

AcciMaps for both stages.

EXECUTION

The execution of the analysis took place over several sessions, as indicated in the timeline below:

Table 1: timeline of the analysis

Date	Activity	Parties
16-06-2017	Preparation of 1st DDOS workshop	BCM, UT
06-07-2017	1st DDOS workshop	Alpha, UT
14-07-2017	2nd DDOS workshop	Alpha, UT
15-09-2017	Preparation of 3rd DDOS workshop	BCM, UT
03-11-2017	Formulation of recommendations onset	BCM, UT
17-11-2017	3rd DDOS workshop: Establish AcciMap of response phase	BCM, R&C, UT
24-11-2017	Formulation of recommendations response phase	BCM, UT
08-12-2017	Compare recommendations with earlier analyses	BCM, UT

Note: BCM: Business Continuity Manager – the person who is responsible for enabling the organization to continue business critical activities during the most challenging circumstances; UT: Researchers from University of Twente; R&C: representative from Risk & Compliance – the department responsible for corporate risk management and for follow up on defined risk mitigation plans.

Introduction to AcciMap

AcciMap has been thoroughly described in the literature (Branford *et al.* 2009; Salmon *et al.* 2014; Svedung and Rasmussen 2002; Underwood and Waterson 2013; Underwood and Waterson 2014). As a short introduction, AcciMap is an epidemiological incident analysis method that takes the complete socio-technical system into consideration. Part of the method is a diagram that links all causal factors to their causes, stopping only at causes for which further analysis is not useful given the incident. The Generic AcciMap Method we apply, contains three levels of causal factors: the physical / actor level, in which actions and malfunctioning equipment play a role; the organizational level, in which organizational errors and malfunctions play a role, and an external layer, subdivided into regulatory, government and society. Each causal factor is part of one layer and the causal factors that are part of the physical/actor level and the organizational level are considered in formulating recommendations for the organization suffering from the incident.

Workshops

The workshops consisted of an introduction to AcciMap including an example and subsequently performing steps 1 – 8 of the *Generic AcciMap Method.* (*See* Sidebar 1). We made a slight change to steps 2-4: we had the participants write out the causal factors on sticky notes directly and we discussed the level on which they had to be attached in the group as we put the notes on the overall AcciMap paper. The group identified 64 causal factors, and we did not finish all steps in one workshop. The factors were identified using two methods: first, we let the participants individually formulate causal factors without any other input than the introduction of AcciMap. We then presented the participants with the table with *categories of cause* as listed in Branford's article. These are listed in Sidebar 2. This helped in formulating additional causal factors.

1. (Create a blank AcciMap format on which to arrange the causes)
2. Identify the outcome(s)
3. Identify the causal factors
4. Identify the appropriate AcciMap level for each cause
5. Insert the causes
6. Insert the causal links
7. Fill in the gaps
8. Check the causal logic
9. Formulate Safety Recommendations

Sidebar 1: the 9 steps in the Generic Accimap Method

During the discussions in the first workshop, we observed that the participants not only included the causal factors leading to the incident, but also factors that impacted the resolution of the incident. We decided to make two groups of causal factors and two different AcciMaps: one for the onset of the accident and one for the resolution or response phase. We then concentrated on the onset of the accident and the completion of steps 5-8.

The onset of the accident

During the first workshops we were able to identify some of the causal links. These were recorded and modelled in a preliminary AcciMap which we completed in the second workshop. We then decided to review the final AcciMap for the onset in a smaller committee (the researchers and the representative of the company for Business Continuity). In that meeting, we also formulated the safety recommendations.

The resolution of the accident

As the workshops take quite some effort, we decided to do steps 2-9 for the response phase in a smaller committee: the two researchers and two representatives of the company: one from Risk & Compliance, and one from Business Continuity. This resulted in a second set of recommendations.

1. Financial, such as (s/a) cost cutting
2. Equipment and Design, s/a poor quality equipment
3. Defences, s/a missing alarms
4. Communication and Information, s/a inadequate knowledge
5. Auditing and Rule Enforcement, s/a missing internal auditing
6. Organizational Culture, s/a incompatible goals
7. Risk Management, s/a inadequate security
8. Manuals and Procedures, s/a missing manuals
9. Human Resources, s/a insufficient staff
10. Training, s/a inadequate exercises

Sidebar 2: Branford's Categories of Cause

Formulating the safety recommendations

We formulated safety recommendations in a manner analogous to Branford, with a few changes:

- We formulated safety recommendations per causal factor. This way, we had a structured approach to go through the different causal factors, and we made sure that we covered all three types of recommendation per causal factor.
- Branford has a heuristic to formulate recommendations: she uses the terms *Change, Control* and *Compensate* to describe different types of recommendations. *Change* means what can be rectified directly, *Control* means what can you do to control the outcome of an incident and *Compensate* means what can you do to compensate for the consequences. This heuristic we reused, but as our audience had trouble applying those terms, we chose to use the terms *Prevent, Mitigate* and *Compensate*. These terms had the same meaning in our applications, but they were more easily understood by our audience

RESULT

Table 2: Identified causal factors and recommendations per stage and AcciMap level

Stage	Number of Causal Factors			Number of Recommendations		
	External	Organizational	Physical /Actor	External	Organizational	Physical/Actor
Onset	11	17	4	0	54	6
Resolution	4	16	12	0	50	26

From previous research (Bukhsh *et al*. 2019) we found that Telecommunications operators do not use structured methods. Their analysis mostly concentrates on the physical parts of an incident, and the activities of the different actors in the incident. Applying AcciMap clearly adds more levels to the picture, as can be seen from Table 2. This was also the feedback we got from the professionals in company Alpha.

After analyzing all causal factors, we noticed that both the onset of the incident (the causal chain leading up to the incident) and the resolution of the incident (the causal chain leading up to the resolution of the incident, or back to "business as usual") were of interest to Alpha. This makes sense: from a prevention perspective, the chain of events leading to the accident is relevant to prevent a similar incident from occurring again, or at least to make the socio-technical system more robust against future attacks (as this was an incident caused by an attack, and attacks will happen). But given the fact that attacks will happen, and Telecommunications operators are always vulnerable to attacks, while hackers are resourceful, an operator will always have to plan for situations in which they could not prevent a successful attack. This means that resolution of the incident is paramount in that case: the quicker the operator is back in business, the lower the damage in terms of costs, lost revenue and damage to corporate image.

Table 3: Identified recommendations per Category of Cause and AcciMap level

Stage	Category of Cause	Organizational	Physical/Actor
Onset	Risk Management	17	
	Finance	7	
	Equipment & Design	12	6
	Defenses	5	
	Communication & Information	3	
	Auditing & Rules Enforcement	10	
Resolution	Information Sharing	6	
	Technical issues extending crisis period		6
	Crisis Management	17	4
	Staff	8	
	Training	2	
	Company Culture	5	
	Crisis Facilities & Tools	12	16

For the onset, we have grouped the recommendations according to the different categories of cause as discussed by Branford. When analyzing the recommendations for the resolution phase, these categories did not add to the understanding and we grouped the recommendations differently, as indicated in Table 3. This is not entirely unexpected: the onset can be covered by generic strategic, tactical and operational processes. All recommendations are meant to improve those processes or – if missing – define and implement them. The processes around the resolution phase are more crisis oriented: the resolution stage is one of crisis management: getting business back to normal as soon as possible in a situation in which not all information is available and the cause of the crisis is still there. In this phase, more recommendations have been formulated on the physical and actors level. This can be understood as follows: crisis facilities can be planned and prepared beforehand, but actions during the crisis (usually a situation with at least some characteristics that cannot be predicted) require a certain amount of improvisation – a feature of the actor layer.

Table 4: Comparing recommendations between investigations

Category of Cause	AcciMap	Alpha's investigation	Accountancy Firm
Risk Management	17	0	0
Finance	7	4	0
Equipment & Design	18	6	0
Defenses	5	0	0
Communication & Information	3	0	1
Auditing & Rules Enforcement	10	0	0
Information Sharing	6	0	1
Technical issues extending crisis period	6	0	1
Crisis Management	21	6	10
Staff	8	0	0
Training	2	0	2
Company Culture	5	0	0
Crisis Facilities & Tools	28	4	0
Total	136	20	15

Feedback from telecommunications operator

After applying the method to the incident, Alpha found that

- AcciMap really helps to get more insights in the context of an incident
- AcciMap is a structured method to find recommendations for the organization as a whole
- It is very time consuming
- It is not appropriate for the resolution of the incident itself, only as post mortem after the incident has been resolved
- Alpha intends to use this method in the future for the post mortem of larger incidents. We are currently preparing a second case study with Alpha, using a less-time-consuming version of AcciMap.

DISCUSSION AND CONCLUSION

Answers to the research questions

Do epidemiological methods add more value to the incident analysis in Telecommunications services?

According to Alpha, AcciMap adds more value than the ad hoc, sequential methods they used before. This is also reflected by the number of actionable recommendations when compared to the method employed by Alpha (136 vs 20). The number of recommendations from the accountancy firm is less relevant as a comparison number, as their recommendations were based on comparing Alpha's crisis organization to the firm's ideal model of a crisis organization.

Is the Generic AcciMap method a viable method for analyzing Telecommunications incidents?

According to Alpha, the method is viable for large incidents, given the investment in time and effort. For quick resolution, an epidemiological method is less apt: during the resolution phase, time is of the essence and a sequential method is more appropriate. This is also confirmed by our experience in applying FTA as part of this analysis – which took far less time. As far as we could determine from discussions with Alpha's staff, this is also in accordance with their mental model for quick incident resolution.

Other findings supporting AcciMap as a method for incident analysis in Telecommunications

The case study yielded more results than just the answers to our research question.

Difference between onset and resolution

During the analysis of the incident, we found that the experts in Alpha listed causal factors that lead to the incident as well as causal factors that prolonged the incident. To keep things manageable, we decided to create two different AcciMaps (onset and resolution) in order to give some structure to the discussion. This proved helpful and as a result, we have been able to also generate recommendations for crisis management (the brunt of the resolution phase in this case).

For Alpha, the resolution phase was as interesting as the onset to the accident. Although Alpha is keen on preventing the next incident, they do realize that incidents will happen and that quick resolution is also important.

Applicability to crisis organizations

The resolution phase is of further interest, as it is actually applying AcciMap not to an incident, but to a crisis organization: how did Alpha respond to the crisis and what lessons can be learned from that? Of the 76 recommendations for the resolution phase, at least 49 where directly related to crisis management and crisis facilities. This means that AcciMap may also be a very interesting method to analyze crisis resolution and by its extension, crisis organizations.

Difference between strict focused investigation and broad investigation

The large difference in recommendations from the AcciMap method and from the two other investigations can partially be explained by the stricter focus of the latter: both Alpha's investigation and the accountancy firm's restricted themselves (consciously or unconsciously) to only a part of the problem: Alpha's to the technical and security aspects of the incident, the accountancy firm's to the crisis management aspects. This may be an added benefit of AcciMap or indeed of any epidemiological method: it forces you to look at the incident from all angles, yielding recommendations in areas where you would beforehand not expect them, simply because you

did not consider them.

Other findings suggesting opportunities for improvement of AcciMap when applied to incident analysis in Telecommunications

Large number of actionable recommendations due to structured approach of formulating recommendations

The structured approach of formulating recommendations lead to a large number of actionable recommendations: as each causal factor was considered individually, each factor could give rise to a large number of recommendations. In our case, the average number of recommendation per causal factor in the organizational and physical/actor level was 2.5 for the resolution phase and even 2.9 for the onset. Such a large number of recommendations calls for central co-ordination of follow up and prioritization of the recommendations. We did not go into the way how to prioritize them, although several methods spring to mind (based on cost / benefit, or risk based for example).

Time consumption

As can be seen from the timetable in Table 1, the method is time consuming. It took three workshops with multiple staff, which is costly. This means that the method – in this version – is only feasible when dealing with incidents that have a severe impact on the business. This also signals an opportunity for improvement: if this effort can be reduced, the method will be easier to apply and the cost-benefit relation will improve.

Furthermore, much discussion centered around the assignment of blame: it was hard to keep the discussion away from the blame game. This may be an aspect of the organization itself, but we think we may be able to avoid these discussions by first concentrating on the physical layer of the incident – something that can be done relatively neutral and factual. After the core mechanism of the incident has been established, this small success may set a better atmosphere for the organizational discussions.

Alpha's Business Continuity Manager suggested to have a short video message from the CEO before starting an incident analysis to emphasize that the analysis should uncover *all* sources of failure with the express purpose of preventing future incidents, while also admitting that not all measures may be implemented for reasons of time or due to monetary constraints.

Lack of IT systems in the levels for AcciMap

We noticed that the AcciMap when applied to telecommunications may benefit from adding a sublevel to the physical/actor and the organizational level: Systems and Software are as important as actors and organizational aspects. We did not consider this division in this analysis, but it may be beneficial to do so in further research.

Changes to AcciMap

Changes to the model

In order to give software or digital issues a more prominent place in the AcciMap (which we feel is necessary to adequately describe phenomena in technical environments), we propose the following:

- Describe the external and the organizational layer each from the point of view of three aspects: social, physical and digital.
- Describe the outcomes in terms of operational and technical aspects
- Describe the organization in terms of its components (organizational units) and the causal factors as relating to an aspect of those components (financial, communication, information flow, et cetera).

Changes to the method

For efficiency reasons, and to get everyone on board and avoid spending too much time on avoiding blame assignment, we propose a new approach for the method. Note that it may be hard to impossible to convince the experts that non-events do not exist, or to prevent non-events from cropping up. This is why we added step 2 in the approach below. These are the proposed steps:

1. Establish the physical core mechanism of the accident including the causal flow.

2. Find mitigations. This may be in terms of failure or absence of barriers, norms and entities.
3. Find how the mitigations would have influenced the causal flow and model this.
4. Use a heuristic to find recommendations (we follow Branford in her approach to look at three aspects: prevention of an event, controlling an event and compensating for the outcome of an event).
5. Prioritize the recommendations –many methods have been described in the literature.

Future Work

We are currently applying the adapted method in a case study with another telecom operator, and will use it also in a second case study at Alpha. These studies will test the changes to model and method we propose and supply more evidence to test the claim of usefulness. Enhancing efficiency and applicability to telecommunications will in our opinion greatly improve the value of this method to operators. Greater value may lead to widespread use, giving more opportunity to learn from these incidents.

REFERENCES

Branford, K., N. Naikar and A. Hopkins (2009). "Guidelines for AcciMap Analysis". Learning from High Reliability Organisations, CCH Australia Ltd.

Bukhsh, F.A., E. Vriezekolk, H. Wienen and R. Wieringa (2019). "Availability Incidents in the Telecom Domain: A Literature Review", Cybersecurity and Safety Group, University of Twente, The Netherlands (pre-print)

Salmon, P. M., N. Goode, F. Archer, C. Spencer, D. McArdle and R. J. McClure (2014). "A systems approach to examining disaster response: Using AcciMap to describe the factors influencing bushfire response." Safety Science **70**: 114-122.

Svedung, I. and J. Rasmussen (2002). "Graphic representation of accident scenarios: mapping system structure and the causation of accidents." Safety Science **40**(5): 397-417.

Underwood, P. and P. Waterson (2013). "Accident analysis models and methods: guidance for safety professionals."

Underwood, P. and P. Waterson (2014). "Systems thinking, the Swiss Cheese Model and accident analysis: a comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models." Accid Anal Prev **68**: 75-94.

Vesely, W. E., F. F. Goldberg, N. H. Roberts and D. F. Haasl (1981). "Fault tree handbook."

Wienen, H.C.A., F.A. Bukhsh, E. Vriezekolk and R.J. Wieringa (2019). "Learning from accidents: a systematic review of accident analysis methods and models." IJISCRAM 2019 (In Press)

Describing and Forecasting the Medical Resources assignments for Disaster Medical relief Forces Using an Injury-Driven Ontology Model

Min Zhu
6th Medical Center of General Hospital of PLA, Beijing, China
Institute of Public Safety Research(IPSR), Tsinghua University, Beijing, China
Beijing Key Laboratory of City Integrated Emergency Response Science, Beijing China
zhum14@mails.tsinghua.edu.cn

Ruxue Chen(Co-first Author)
6th Medical Center of General Hospital of PLA, Beijing, China
13381207330@126.com

Shaobo Zhong
Beijing Research Center of Urban Systems Engineering, Beijing China.
zhongshaobo@tsinghua.edu.cn

Quanyi Huang
Institute of Public Safety Research(IPSR), Tsinghua University.Beijing, China
Beijing Key Laboratory of City Integrated Emergency Response Science, Beijing China
qyhuang@tsinghua.edu.cn

Jing Ouyang
6th Medical Center of General Hospital of PLA, Beijing, China
18600310831@163.com

Guang Tian*(Corresponding Author)
6th Medical Center of General Hospital of PLA, Beijing, China
18911003710@126.com

ABSTRACT

Available medical resources are the basis of efficient disaster medical relief. The medical resources assignment for disaster medical relief forces is usually fixed. However, the injury condition distribution changes in different disaster and so does the demand for the medical resources. So the assignment of medical relief forces should be more flexible and based on the injury. We analyzed the component parts and rules of disaster medical relief, defining the related concepts and rules. Then, we constructed the describing rules of injury-treatment-medical-technique-resource-assignment process. Based on these, we established the ontology of disaster medical relief system and the injury-driven medical resources assignment ontology model (MRAOM). We used the model to describe the medical relief situation after earthquake to demonstrate the model could describe complicated situations. We also used the model to describe and forecast the medical resource assignment of treating batch wounded to demonstrate the model's validity.

Keywords

Medical Resources Assignment, Disaster Medical Relief, Injury-Driven Ontology Model.

INTRODUCTION

Sudden-onset disasters could cause mass casualty incidents in short time, creating a surge in demand for emergent medical service (Reinhardt et al., 2011). Studies have shown that approximately 90% of the injuries are reported and rose in the first 7-14 days after disaster, so the disaster medical relief in the first 3 weeks are

crucial.(Zhang et al.,2012; Zhang et al.,2011; Akbari et al.,2004)

Generally, the disaster medical relief system is divided into 3 levels.(Miao and Nie,2004; Lu,2008) 1st level provides first aid which uses rapid effective methods to save life on the spot, such as basic life saving, hemostasis and wounds binding techniques. 2nd level provides advanced life saving methods which include lifesaving surgeries, severe shock correcting and other techniques aiming to decrease mortality and disability. 3rd level provides all kinds of medical services which are necessary to cure injuries and patients. 1st level is consisted of all kinds of medical rescue teams that could get to the spot as soon as possible. 2nd level is consisted of normal-function municipal hospitals nearby. 3rd level includes comprehensive healthcare organizations most of which are facilities of Department of Health Care. Studies have shown that the mortality of injuries within 1st level is the highest, while the 2nd level takes the second place. (Jiang et al.,2012) A large percentage of injury deaths occur on the field before evacuation to 2nd level medical facilities. (Cranmer,2005) This indicates that great emphasis should be placed on the 1st and 2nd level during a disaster medical relief.

Most medical institutions in the disaster area could be damaged, so the 1st level and part of 2nd level medical institutions are consisted of strengthen medical forces from the non-disaster areas, inside or outside the country, civilian or military. (Auerbach et al.,2010) Strengthen medical forces should meet the medical demand in the disaster area. The efficiency of first aid is crucial, and the basis of the efficiency is the availability of the right medical resources. Most strengthen medical forces' resources assignment is fixed. But the real needs of the resources could change according to the different injury condition distribution in the different disaster scene. So sometimes the availability of some medical resources would be low and affect the medical rescue efficiency.

This research aims to describe and forecast the medical resources assignments based on different medical relief forces and different injury condition distributions. However, emergency medical rescue is complicated, and the composition of medical forces are diversified. We choose ontology method to construct the injury-driven model to express the complicated medical rescue knowledge and help multiple-source strengthen medical forces to understand the model. Thus, organizers of disaster medical relief could have an increased awareness of the overall disaster medical rescue environment, allowing them to make better decisions more rapidly.

This article divided the process of medical resources assignment modeling into four parts: 1.The description and definition of component parts of the medical relief; 2. The definition of rule of disaster medical relief and injury medical treatment; 3. The description and definition of injury treatment profiles and medical resource assignment rules; 4. Constructing ontology model of medical relief entities and domain rules. Finally, we gave two examples to demonstrate the usage of the model.

ANALYSIS OF THE MEDICAL RESOURCES ASSIGNMENTS FOR DISASTER RELIEF

Generally, medical resources assignment is part of emergent readiness plan. The description of the emergent readiness plan needs to choose and reconstruct emergent domain knowledge. (Mendonca and Wallace,2007) As for the description of medical resources assignment, both medical and emergent domain knowledge should be chosen and reconstructed. Emergent readiness plan knowledge modeling is a interdisciplinary project and tremendous progress has been made about this modeling. Some researches proposed to construct the relationships between mission and executive condition based on an incident-mission framework. (Mors et al.,2005) Some described the structure and dynamics of the emergent organizations based on the extended sequence locus language. (Hoogendoorn et al.,2005) But most methods of illustrating the emergent readiness plan could not solve the problem of knowledge sharing.

Ontology is a knowledge description method that is easy to conceptualizing, sharing and illustrating.(Grigoris and Frank,2008) This method could clearly and accurately describe the domain concepts and their relationships. It could also describe the complex domain knowledge and its feature. So ontology could be an effective method to construct the medical resources assignment modeling.

The basic idea of describing and forecasting the medical resources assignment using an ontology model is as follow: 1. Different level of care has different treatment goals and contain different medical facilities with different medical treatment units. 2. When different injuries got to different medical facilities and went through different medical treatment units, they would accept different medical techniques to improve their condition. 3. The basis of different medical techniques is different medical resources. So the determination of medical resources assignment is based on both injury conditions and the function of medical facility.

The Component parts of the Disaster Medical Relief

Generally, most of the medical institutions in the badly damaged areas within the disaster zone are damaged. However, most injuries would occur in these areas and need medical treatments urgently. Most strengthen

medical relief force would arrive in these areas and strengthen the local medical facilities. These strengthen forces belong to 1st level or 2nd level medical care aiming to lifesaving and reducing disability. The forms of these forces are rescue teams with highly mobility or field hospitals with the placement of resuscitative surgery units as close to the first responder as possible.

According to systematical point of view, we could consider the whole level of care or one medical facility as one system. Then we could divide the system into small medical treatment units according to the medical function. Every medical function units are related to different medical techniques. Different rescue team or field hospitals could choose the placement of different medical function units with diversified medical techniques based on the goal of mission as well as the possible injury condition distribution. Carrying out different medical techniques would need different medical resources. So in different mission scenes, the same rescue team or field hospitals could have different multiple medical function units with different medical resources assignment.

Definition 1 Define the whole set of medical function units as: $B=\{b_1,b_2,\ldots,b_n\}$.

Definition 2 Define certain rescue team's or field hospital's set of medical function units as: $B_i=\{\quad\}$.

The medical function unit b_i could not be divided or it couldn't execute any medical treatment. For example, Pre-operation unit could not be divided or it couldn't finish the works before an operation.

Meanwhile, B_i is the subset of B which means $B_1,B_2,\ldots,B_n$ should satisfy the condition： B=B

Particularly, every B_i is not definitely mutual independent, which means there could be intersections between B_is. That means B1,B2,…,Bn don't have to satisfy the condition $B_i \cap_{i\neq j} B_j = \emptyset$.

Definition 3 Define the whole coverage of the medical function of the units as:

Then the coverage of the medical function of the international medical relief force, including rescue team or field hospital, is: π'

The brief structure of the international medical relief force is showed in figure 1.

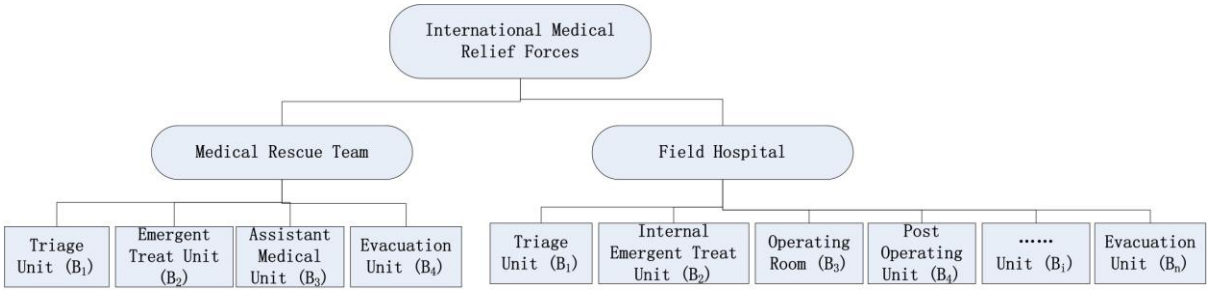


Figure 1. Brief Structure of the International Disaster Medical Relief Forces

Different function medical unit could carry out different medical techniques. Part of the relationship of function unit, medical techniques and medical resources types are showed in table 1. The medical resources which are used for the same medical techniques are combined together and signed with a specific number.

Table 1. Part of the relationship of function unit, medical techniques and medical resources types

Function Unit	Medical Technique Description	Medical Resources	Resource No.
Triage	Measure Vital Signs	Sphygmomanometer; Stethoscope	1
	Assessment &Evaluation of Patient Status	Otoscope & Opthalmaloscope	2
	Bowel Sounds Assessment	Stethoscope	3
	Circulation Check	Stethoscope	3
	Blood Gas Estimate	Analyzer Clinical Chemistry	4
	Determine Electrolyte Levels	Analyzer Clinical Chemistry	4
	.....	.....	...

Emergent Treat	Emergency Control of Hemorrhage	Bandage (Elastic or Gauze); Dressing First Aid Water-Gel; Sponge Surgical Guaze; Tape Adhesice Surgical Woven	11
	Establish Adequate Airway	Airway Nasopharyngeal / Pharyngeal	12
	Start Intravenous Infusion Site	Catheter & Needle Unit; Infusor Pressure Blood Intravenous; Intravenous inj Set; Alcohol Impregnated Cotton	13
	Insert Oro/Naso Gastric Tube	Lubricant Surgical Tube; lidocaine Hydrochloride Jelly Tube; Tube Stomach Surgical Plastic Lumen	14
	Cardiac Resuscitation	Defibrillator Monitor-Recorder; Heparin Sodium injection; Injector Tube plas Medication Needle Cart; Defibrillator Auto External	15
	Catheterization-Suprapubic	Catheterization Kit Urethral Bot-outlet Drain Bag; Lidocaine Hydrochloride Jelly Tube; Lubricant Surgical Tube	16
	.....	.....	...
Op-Room	Operation Preparation	Bag Sterilization Biohazard Disp; Detergent Enzymatic Cleaner Instrument Surgical Tube; Disinfectant Surgical Instrument Cidex	31
	Patient Preparation	Razor Surgical Preparation Disposable Plastic; Skin Preparation Kit Pre-Operative Sterile	32
	Induce/Maintain General Anesthesia	General Anesthesia Equipment Set	33
	Emergent Surgeries (hemostasis surgery, skull drilling drainage, gastric excision repair anastomosis, resection of spleen or kidney, ...)	Clamp Artery; Forceps Hemostatic; Forceps Intestinal; Forceps Tissue; Handle Surg Knife; Holder Suture Needle; Knife Sternum; Bone Surgery Corrosion Resisting; Retractor Abdominal; Retractor General Operating; Retractor Rib; Retractor Vein; Scissors General Operating Surgical; Cannula Brain Frazier	34-40
	Clean & Prepare Surgical Instrument Sets	Wash Basin; Cleaner & Lubricant Surgical Instrument Can; Detergent Enzymatic Cleaner Tube; Disinfectant Surgical Instrument Cidex; Surgical Towel Pack	41
	Assess Electrolyte Levels	Analyzer Clinical Chemistry	4
.....	.....	.....	.....

Definition 4 Define all the medical techniques as: $T=\{t_1,t_2,\ldots,t_n\}$. Then the medical techniques within a certain medical function in a certain medical facility of a certain level of care is: $Ti=\{L,F,U\backslash t_1,t_2,\ldots,t_k,\ t_k \in T\}$. L represent level of care, F represent medical facility, U represent medical function unit.

Medical resources are the basis of carrying out the medical techniques.

Definition 5 Define all the medical resources as: $R=\{r_1,r_2,\ldots,r_n\}$. Then a certain medical technique ti related medical resources are: $Ri=\{r'_1,r'_2,\ldots r'_n\}$ and $Ri \subset R$

Medical resources are mainly the equipments, instruments, medicine and medical staff. According whether to the resource could be reused or not, medical resources could divided into consumable resources and non-consumable resources.

Rules of Disaster Medical Relief

From the analysis of the component parts of the medical relief, the relationship of medical resources and medical demands are reflected by the treatment of the injuries going through the medical facilities in the different level of care. So the rules of disaster medical relief is the main ground of the medical resource

assignment. When every different injury goes through the medical facility, the injury condition gets better and certain medical resources are consumed. So generally, the rules of disaster medical relief are established in the form of "if…then". This means the injury treatment profiles are based on the injury condition. Its formalized definition is as follow：

Rule 1 Injury Treatment MITDomainRules=（InjuryCondition, TreatmentGoal）

This represent that when the injury satisfies the logical condition expression InjuryCondition, the TreatmentGoal should be achieved.

This rule expresses the relationship between injury condition and the treatment goal that the medical facility should achieve. TreatmentGoal is the most urgent medical treatment goal the medical facility should achieve based on the injury condition. It includes the chosen of care level, medical facility and medical function units in order to achieve the treatment goal. For example, for a batch of burned injuries, the treatment goal is to relieve or control the injury hazards and sustain life. Then we should choose the nearest rescue team belonging to the 1st level of care and carry out basic and advanced life supporting medical techniques.

Injury Treatment Profiles And Medical-Technique-Resource Relation Rule

The core rule of medical resources assignment is how the medical technique in the medical function units related to medical resource based on the injury condition. This part of rules include injury treatment profiles and medical-technique-resource-assignment relationship rules.

Injury Treatment Profiles

Injury treatment profile is a treatment process describing series of medical treatments which are accepted by certain injuries when they go through certain medical facility. According to different injury conditions, the profile set is consisted by different treatment process subsets. Its formalized definition is as follow.

Rule 2 Injury treatment profiles within the medical facility UstandardProfile=（goal, {treatmentProcess$_1$,…, treatmentProcess$_n$}）

Goal stands for the treatment goal which this medical facility should complete to relieve the injury hazards or improve certain physiological function. TreatmentProcess$_i$(1 n) stands for the treatment process that the medical facility should take to complete the treatment goal.

Treatment goal is a status that the injury should get after going through the medical facility. It is the basic line of injury medical treatment and its formalized definition is as follow.

Rule 3 goal=(name, params, input, output, interval)

Name stands for the medical facility's name. Params stands for the parameter description of the treatment goal. Input and output stand for the injury condition before and after going through the medical facility. Interval=[startTime, endTime] stands for the time interval that the injury goes through the medical facility which is also the interval time between the start and end point of injury treatment.

Treatment process describes a certain treatment pathway within the medical facility when the injury condition satisfy certain condition. It is constituted by a series of medical techniques with complex time relationship. Its formalized definition is as follow.

Rule 4 TreatmentProcess$_i$=(precondition$_i$, medicaltechniqueflow$_i$, timeConstraints$_i$, anotation$_i$)

Precondition$_i$ stands for the precondition of injury when accepting the treatment process. Medicaltechniqueflow$_i$ indicates series of medical techniques which are used in the treatment process. TimeConstraints$_i$ presents the time constraint set of using the medical techniques and the key point of the treatment process. Anotation$_i$ stands for other information we should take notice when using the treatment process.

The logical relationship of treatment process and its time constraint：

1. Logical relationship of treatment process.

We use flow model based on PetriNet to describe the medical techniques and the precondition of carrying them out. The process is constituted by series of medical technique and the routing structure between them. Medical technique is the basic element of the treatment process. The routing structure between them could be described

by 4 logical relationships, including sequent, parallel, choose and circulate control. This routing structure could describe the logical relationship and executing order of the medical techniques. Any treatment process could be described through reasonable organizing of the medical techniques and the four basic routing structure.

Taking the treatment process of the injury whose spine might be hurt as an example to show the modeling of treatment process. As figure 2 shows, the treatment goal is to evacuate the injury without hurting his/her spine's function. So the medical facility should determine whether or not use spinal arthodesis before evacuation. If the injury type is penetrating trauma, locating in head & neck or limbs (pre 1), then we should check the injury's neurologic function. If neurological disorder exists, which is pre1-1(t3), then we should use spinal arthodesis before evacuation (t7). If neurological disorder doesn't exist (pre1-2(t4)), then the injury could be evacuated immediately. If the injury type is blunt trauma (pre2), then we should check and evacuate the injury's consciousness. If the consciousness change get GCS<15 (pre2-1(t5)), then we should use spinal arthodesis before evacuation (t8). If the injury consciousness change get GCS≥15 (pre2-2(t6)), then we should check and evacuate whether or not the spine exists pain or softness, the neurological function has obstacles and the anatomical structure of the spine changes. If any of this three conditions exists (pre2-2-1(t9)), then we should use spinal arthodesis before evacuation (t11). If none of these conditions exists (pre2-2-2(t10)), then we should consider whether or not there exists the injury mechanism of the spine. If the injury mechanism doesn't possibly exist (pre2-2-2-1(t12)), then we could evacuate the injury without spinal arthodesis. If the injury mechanism possibly exists (pre2-2-2-2(t13)), then we should determine following conditions exist or not: 1) evidence shows that the injury take alcohol or drug; 2) other traumas; 3) couldn't normally exchange. If none of these conditions exists (pre2-2-2-2-1(t14)), then we could evacuate the injury without spinal arthodesis. If any of these conditions exists (pre2-2-2-2-2(t15)), then we should use spinal arthodesis before evacuation.

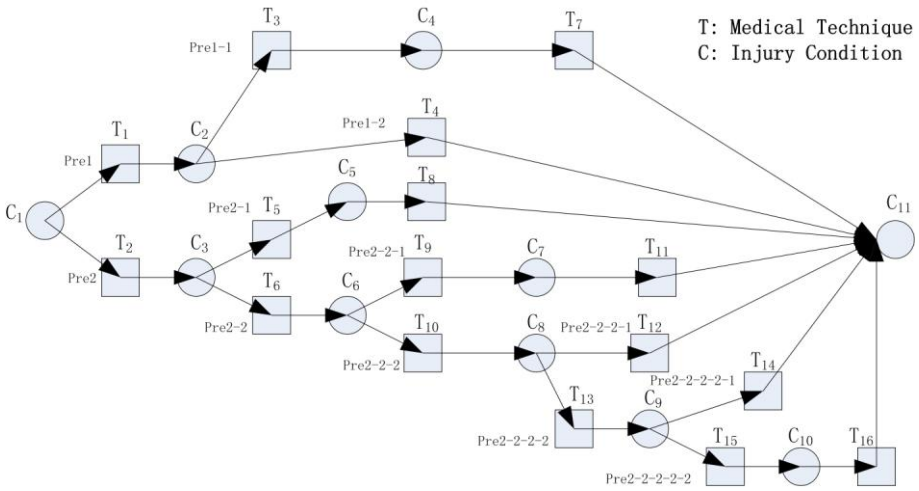


Figure 2. Brief Treatment Process Logical Relationship of The Injury With Possible Spine Wounds

2. Time Constraint

The timeliness of disaster medical relief is crucial. Injuries especially critical injuries should be treated within limited time. So there is a complex time synchronization relationship between using the medical techniques.

The time constraint include two types, one is qualitative constraint and the other is quantitative constraint. Because of the complexity of injury condition and medical treatment, even carrying out the same medical technique could hardly determine the definite time information. So we could use the qualitative constraint to describe the abstract time condition of using some medical techniques. Generally, we could describe the qualitative constraint of completing certain medical technique using "equal, before, meet, overlap, start, during, after and finish by".

Other medical techniques with definite operating time, we could use quantitative constraint to describe the start and finish time of the techniques. The formalized definition of quantitative constraint could be described as follow:

Rule 5 timeConstraint = (a≤preTimepoint-postTimepoint ≤b)

PreTimepoint and postTimepoint indicate the start time, finish time and injury treatment process reference time point.

Thus the treatment process time constraint could refer to the constraint of medical techniques.

Medical-Technique-Resource Relation Rule

When describing the rule of medical-technique-resource relationship, two points should be strengthened. One is that using a specific medical technique should be based on the medical resources within the medical facility. The other is that the use of a specific medical technique is trigged by the injury condition and should satisfy the time constraint.

We use the PDDL2.1 language based on the artificial intelligence planning to give the formalized definition of the rule as follows.

Rule 6 (Medical Technique) MTechnique= (name, params, precondition, resources, agent, effects , interval, place)

Name stands for the name of medical technique. Params represent the parameters of description. Precondition indicate the specific injury condition. Resources stands for the medical resources which are needed in carrying out the medical techniques. Agent represent the medical relief facility that implement the medical techniques. Effects indicate the treatment effects after using the medical techniques. Interval stands for the time interval that needed for medical technique implementing. Place represent the location.

Rule 7 (Medical Resources)Resources=consumResources ∪nonexpendResources

ConsumResources={cr } represent the set of consumable medical resources. nonexpendResources={nr } represent the set of nonexpendable medical resources. If and only if the medical facility has adequate medical resources, medical techniques could be carried out and could do the deed. Effects={me } stands for the medical effects.

Rule 8 (Consumable medical resources) cr=(logicalExpression, t, n)

This represent the consumable medical resources should satisfy the logical Expression after the medical technique has started t time and the amount should be n.

Rule 9 (Nonexpendable medical resources) nr=(logicalExpression, interval, n)

This represent the nonexpendable medical should satisfy the logical Expression. And during the interval time (interval=(minTime, maxTime)) of medical technique usage, the number of occupied nonexpendable medical resources is n.

Rule 10 (Treatment Effect) tre=<logicalAtom, flag, time>.

This indicate the improvement of the injury condition after t time since the applying of the medical technique. If the improvement is clear, then the sign of treatment effect is flag=true and the logical Atom is added to the injury condition. If not, the logical atom is deleted from the injury condition.

MODELLING OF THE INJURY-DRIVEN ONTOLOGY MODEL

Based on the systematic analysis, we established the medical resource assignment ontology model (MRAOM) by reusing and expanding ABC、OWL-S、SWRL ontology vocabulary & expression. The modeling include knowledge modeling of disaster medical relief system, medical relief domain rules, injury treatment profiles and medical resources assignment rules. The brief structure of MRAOM concepts and relationships is showed in figure 3. The block indicates class, the solid arrow indicates property and the dotted arrow indicates subclass.

Disaster medical relief system ontology modeling

The aim of the modeling is to describe the entity of disaster medical relief system and their relationship, as well as the characteristics of the dynamic changes of the entity during the medical relief process. We promote concepts and relationships of medical relief mission, environment elements, medical demands (injury condition distribution), entity structure, and medical resource based on the ABC ontology model.

Ontology of medical relief mission and medical demand

1. Ontology of medical relief mission

The classification of the mission ontology is according to the different types of the disaster. Different disaster correspond to different medical relief mission ontology. MRAOM uses methods to establish mission ontology as follows.

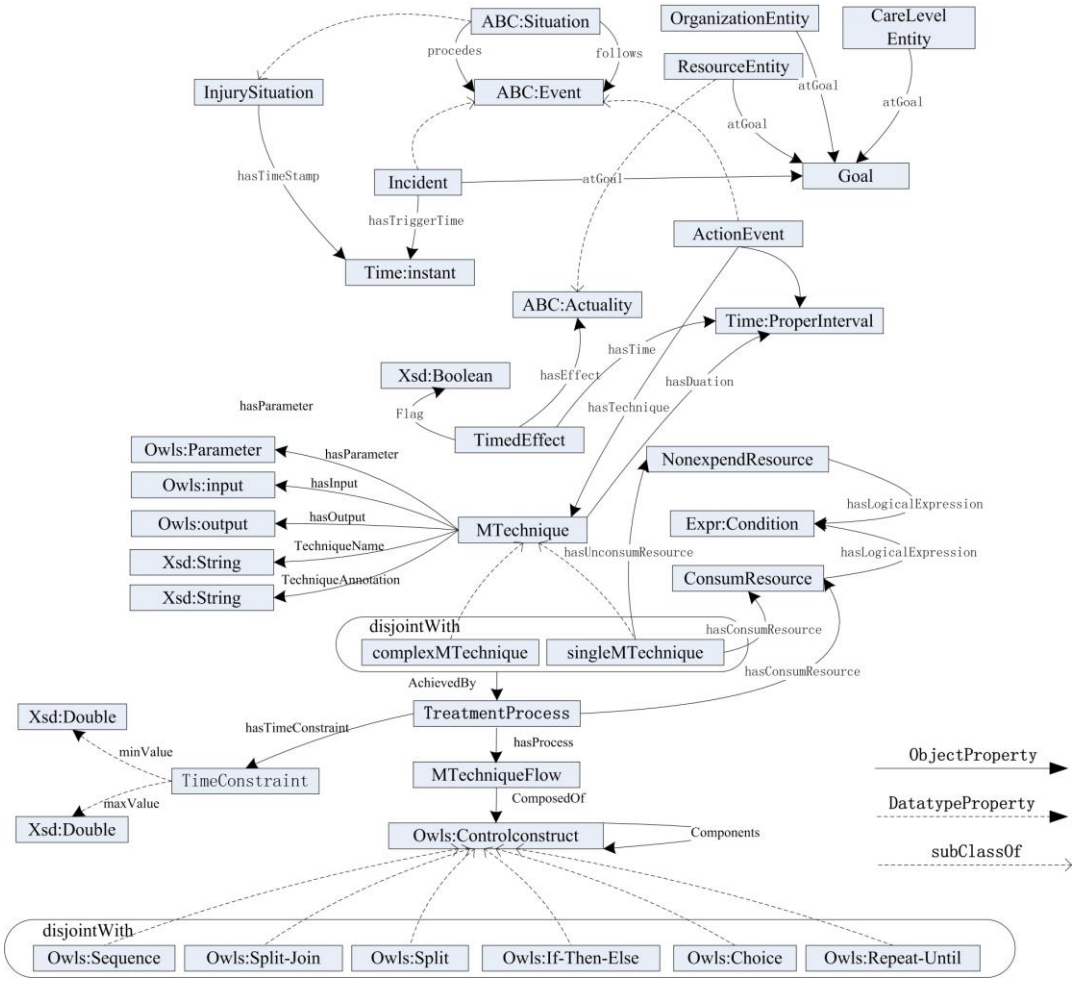


Figure 3. Brief Structure of MRAOM Concepts and Relationships

a) Establish **incident** as subclass of **ABC: event** describe the disaster. Establish properties **asTriggerTime** and **hasLocation,** with range **time: instant** and **location,** indicating the time location of the mission. Establish data attribute **type,** representing the type of disaster, such as earthquake, tsunami and soon.

b) Establish **actionevent** as subclass of **ABC: event.** Establish properties as **hasTask** and **hasInterval** with range **task** and time: properInterval, indicating the type of task and the interval time of executing the mission.

2. Ontology of medical demand

Disaster medical relief demand generally indicates the amount of injuries and the distribution of injury condition at the point of time. So it belongs to situation modeling. Establish **injurySituation** as the subclass of **ABC: situation** indicating the relief demand situation. Establish properties **hasTimeStamp** with range **time:instant.** Establish data attribute **number** and **type** to indicate the amount and condition type of the injuries.

Based on these ontology models, disaster medical relief could be modeled as a discrete event system and describe the relief process as incident series of relief mission and demands. The model could describe the dynamic action based on the changing demands.

Ontology of Medical Relief Entity

Medical relief entities include 3 classes of entity, which are care level entity, medical relief organization entity and medical resource entity. We establish the entity ontology as follows.

1. Establish **treatmentlevelEntity** as the subclass of **ABC: actuality**, indicating the level of care. It include data attribute **name** with range of **string,** indicating the name of care level. Add property **atGoal** with range **Goal**, indicating the treatment goal of the care level.

2. Establish **organizationEntity** as the subclass of **ABC：agent**, indicating the medical facility. It include data

attribute **name** with range of **string**, indicating the name of the medical facility.

3）Establish **resourceEntity** as the subclass of **ABC：actuality**, indicating the medical resources in need.

These ontology are all general concepts in the medical relief domain. In order to describe the entities more specific, we should establish particular entity concept models based on these general models.

Ontology Model of Medical Relief Domain

MRAOM use **Swrl：atom** to indicate fact. As for the problem of using SWRL ontology expressing logical atom conjunction, we use **Expr：condition** to model precondition. Thus, we could realize the ontology modeling of complex logical condition.

Establish class **domainRule** to indicate the rule of medical relief domain. It includes properties of **hasHead** and **hasCondition**, with ranges of **Swrl：atom** and **Expr：condition**, indicating the fact and precondition of the medical relief domain rule.

Ontology Model of Injury-Driven Medical Resource assignment

Medical Technique Flow modeling

Based on the ontology model Owls：process, MRAOM establishes class MTechflow, indicating the medical technique flow which is used in the injury treatment. Add data attribute TechflowName and TechflowAnnotation with range of string, indicating the name and information of the flow. Establish properties hasParameter, hasInput, hasOutput and hasResource. The first three property ranges are Owls：parameter and the 4th is properType&Number, indicating the describing parameter, input injury condition, output parameter and the medical resources that are needed to carry out the medical technique.

When establishing instance of medical technique flow, we should also establish the instance of techflowResource of resource: properType&Number as well as the instance resourceType and resourceNumber of resource: instant, indicating the type and amount of medical resources used in the flow.

The medical technique could be divided into single technique and complex technique. Single medical technique could be done by single medical function unit while complex medical technique should be completed by multiple medical function units.

1. Modeling of single medical technique

Establish class **singleTechnique** as subclass of **Technique**, indicating single medical technique. Establish properties **hasconsumResources**, **has unconsumResources**, **hasTimedEffect**, **atGoal** and **excutedBy**, with ranges of **consumResources**, **nonexpendResources**, **timedEffect**, **goal** and **organizationEntity**, indicating the consumable and non-expendable medical resources, applying effect, goal of applying and executing entity of the medical technique.

Define technique applying effect as **te=<logicalAtom, flag, time>**. MRAOM model the logical atom as **logicalAtom** based on the instant **effectLogicalAtom** of class **ABC：actuality**. In order to stamp time, we establish instant **effectTimeStamp** of **time: interval**, with properties **hasBeginning** and **hasDurationDescription.**

Establish class **TimedEffect** indicating the effect of applying the medical technique after a period of time. Add data attribute **flag**, with range of **boolean**, indicating the sign of applying effect. Add properties **hasEffect** and **hasTime**, with ranges of **ABC：actuality** and **time: interval**, indicating the applying effect logical atom and the time point of generating the applying effetct.

2. Modeling of complex medical technique

MRAOM establishes complexMTechnique as subclass of MTechnique, indicating complex medical technique which should be completed by multiple medical function unit during the injury treating. Add property achievedBy with standardized injury treatment profile. One complex medical technique model could have one or more property achievedBy, indicating multiple pathway that could complete the technique.

Medical Resource modeling

1. Consumable medical resource modeling

(Consumable medical resource) cr=(logical expression, n)

MRAOM establishes class **consumResources**, indicating consumable medical resource, including properties **haslogicalExpression** and **hasConsumStamp**. The ranges of the properties are **Expr: resources** and **number：interval**, indicating the logical expression and the number tag of the consumable medical resource, valuing **instantLogicalExpression** and **consumNumberStampInterval.**

2. Non-expendable medical resource modeling

(Non-expendable medical resource) nr=(logicalExpression, interval, n)

MRAOM uses class **Expr: Resource** to model logical expression **logicalExpression**. Establish instant **intervalLogicalExpression** of **Expr：resource**. In order to indicate the time (interval=(minValue, maxValue)) during which the medical technique occupied, establish the instant minTime of time: interval. The properties **hasBeginning** and **hasDurationDescription** are valued as **techniqueStartTimePoint** and **minValue**. Meanwhile, establish instant **maxTime** of **time: interval** with properties **hasBeginning** and **hasDurationDescription**, valuing **techniqueStartTimePoint** and **maxValue**.

Injury Treatment Profile Modeling

Injury treatment profile could connect the injury condition, medical techniques, medical resource and treatment time together. So the modeling of it is very important.

Establish class **treatmentProcess**, with properties **hasCondition**, **hasProcess** and **hasTimeConstraint**, ranging **instantCondition**, **MTechflow** and **timeConstraint**, indicating the injury condition, medical technique flow and time constraint of the injury profile. Establish data attribute **hasAnnotation**, with range of **string**, indicating the information of the profile.

The modeling of injury treatment process and time constraint are as follows.

1. Modeling of injury treatment process. According to Rule 4, injury tretment process could be described by work flow. Based on the OWL-S modeling idea, MRAOM uses the subclass of **Owls：controlConstruct**, such as Sequence、choice、split+join、iterate、condition、if-then-else、any-order、repeat-while and repeat-until, to realize the modeling of the sequent structure, chose structure, parallel structure and circulate structure of injury treatment process.

In order to describe the treatment steps of injury treatment, MRAOM establishes class **treatmentStep** as the subclass of **Owls：controlConstruct**, indicating a certain step of the injury treatment process. It includes property of **technique** with range of **MTechnique**, indicating the medical techniques used in this treatment step.

As the same as modeling complex process using OWL-S ontology model, the modeling of injury treatment process has tree structure. The root of tree is the instance of class **treatmentStep** and the root node is the instance of subclass **Owls：controlConstruct**.

2. Modeling time constraint

Use the property of **time：properInterval** to express the qualitative time constraint of applying medical techniques. As for quantitative time constraint, MRAOM establishes class **timeConstraint** according to Rule 5. Add properties **hasPreTimePoint** and **hasPostTimePoint** with range of **time：instant**. The value of it indicat the start and end time of the injury treatment. Add data attribute **minValue** and **maxValue**, indicating the minimum and maximum of the quantitative time.

Establish instance **deadlinTimeConstraint** of **timeConstraint**, indicating the time constraint of the medical technique. Its properties are **hasPreTimePoint** and **hasPostTimePoint**, valuing **time:instant** or **referenceTimePoint**, indicating the start and end point of the technique.

RESULTS & DISCUSSION

MRAOM is the model describing the knowledge system structure of international disaster medical relief

resource assignment. It could describe the major elements and rules of disaster medical relief resource assignment and realize the management and modeling of the domain knowledge. In order to display the utility and effectiveness of the model, we take earthquake medical relief as an example to show the usage of the model. The modeling tool is Protégé V4.3. Part of the model usage is as follows.

Model Usage of Describing Medical Relief Situation

The description of medical relief situation include the situation of injuries and the entities of medical relief system. The situation of injuries is described by the amount of injuries, the types of injuries and the severity degrees of injuries. The types of injuries include fracture, burn injury, crush injury, combined injury, etc. The severity degrees of injuries include minor, moderate, severe and critical. Suppose an earthquake had taken place at 7:59 on April 14th, 2010. 120 injuries were found by search team on that very day. The medical staffs at the front reported the types of injuries as fracture, crush injury and combined injury. The medical evacuating units reported that 40% of injuries were severely injured and 20% of the injuries were critical injuries. The medical relief system included two levels of care. The first level included medical rescue teams from local medical facilities and international medical team. The second level included field hospitals composed by medical forces at home and abroad. The model is used to describe the medical relief situation as showed in Figure 4.

I0 indicates the earthquake disaster. The time stamp is "2010/4/1407:59" and the location is L0. This disaster triggered medical relief situation RS0. RS0 described the medical relief situation of "2010/4/14", including the injury situation and medical relief system situation. The RS0 triggered medical relief action RA0 which indicates more emergent medical response actions to save more injuries. As showed in Figure 4, MRAOM describe the disaster medical relief system and its relief process as a discrete event system. The model could also describe the system's dynamic changes and the treatment process sequent changes.

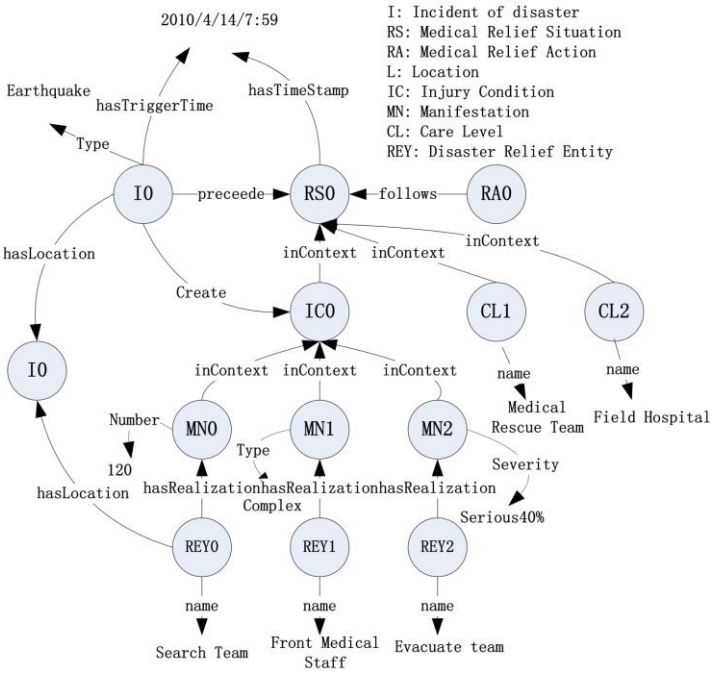


Figure 4. Brief Description of Medical Relief Situation After the Earthquake

Model Usage of Describing and Forecasting the Injury-Driven Medical Resource Assignment Process

The medical resource assignment of international disaster medical relief varies according to different injury condition, different medical relief facility and different type of disaster. Given the limited space available, only the treatment and resource assignment process of batch wounded with possible spine injury treated within the medical rescue team before evacuation was described in figure 5. The basic treatment process was described in figure 2. As showed in figure 5, the resource assignment process based on the injury treatment ontology model is tree structured. The non-root nodes are the subclass incident of class **Owls:construct** describing the structure of injury treatment process. The root nodes are incident of class medicalTreatmentStep, describing the steps of the injury medical treatment process. The combination of Medical Resource No.4, 5, 6, 8, 9, 10 is the possible

medical resource assignment of medical rescue team for treating batch wounded with possible spine injury before evacuation.

CONCLUSION

Medical resources assignment is the basis of international medical relief. This article promote an injury-driven ontology model to describe the process of injury treatment and forecast the resource assignments for different medical relief facility, different injury condition and different disaster type. This ontology model could help medical staffs with different background knowledge from different area or country have common understanding of the complex knowledge in the disaster medical relief domain. The features of this MRAOM describing and forecasting the medical resource assignments are: 1. Based on the systematic point of view, the model abstracts the entities of the medical relief into medical relief system so as to describe the complex features and dynamic activities during the injury treatment process; 2. The model could construct the complex structure and describe time-limited characteristic of the medical resources assignment.

This model describes the features of injury treatment process and medical resources assignment. However, the model is not perfect for lacking enough theoretical validation. The next step of our research would do further theoretical validation and validate the model with real cases. We would also describe the relationship between the medical relief entities and the relationship between different types of the medical resources. Based on these, we would develop a support decision-making system to help the decision makers make resources assignment for specific mission.

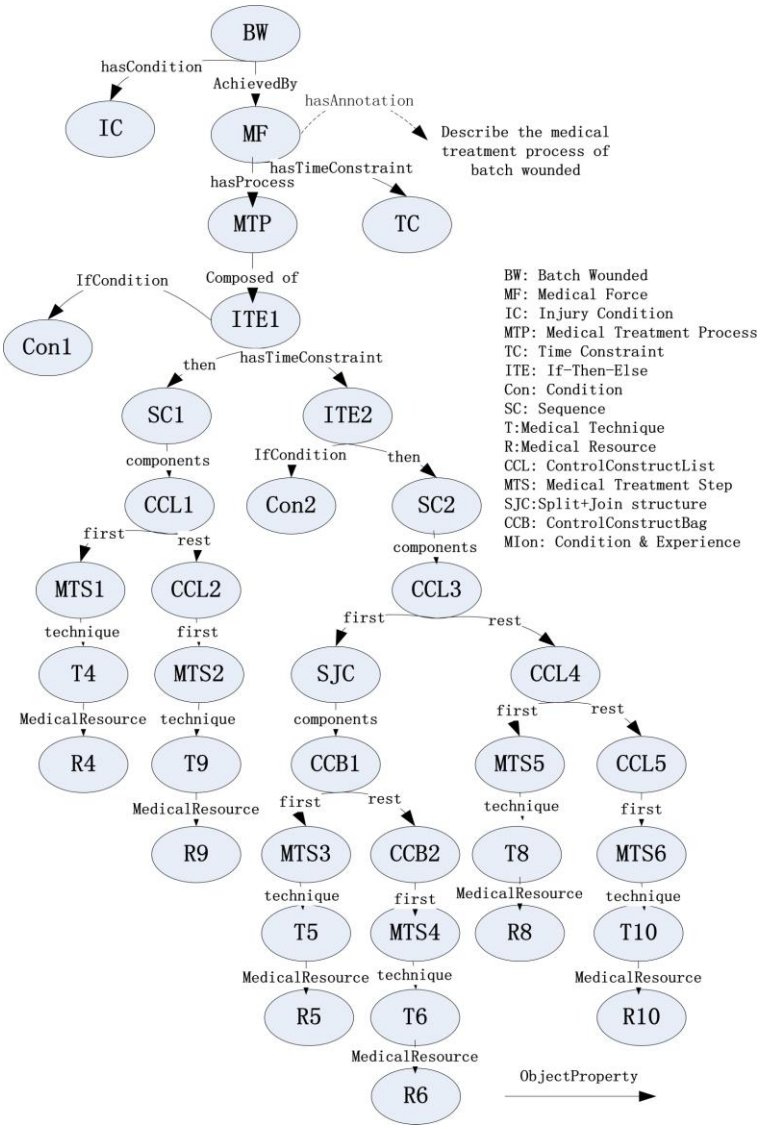


Figure 5. Part of Medical Resources Assignment Process of Batch Wounded Treatment

ACKNOWLEDGMENTS

THIS work was supported by the National Key Research and Development Program of China (No. 2017YFC1405300), Army logistics key projects(#AHJ16J004, #BHJ12L007) Army logistics projects (#CHJ13L008)Army Standardization projects(#BHJ17B042).

REFERENCES

Akbari, ME., Farshad, AA., and Asadi-Lari, M. (2004) - The devastation of Bam: an overview of health issues 1 month after the earthquake, *Public Health*, 118, 403-408.

Auerbach, PS., Norris, RL., Menon, AS., et al. (2010) Civil-military collaboration in the initial medical response to the earthquake in Haiti, *N Engl J Med*, 362, e32.

Cranmer, HH. (2005) Hurricane Katrina. Volunteer work-logistics first, *N Engl J Med*, 353, 1541-1544.

Grigoris, A., Paul, G., Frank, VH., et al. (2012) A semantic web primer. PHI press, India.

Hoogendoorn, M., Catholijn, M., Popova, V., et al. (2005) Formal modeling and comparing of disaster plans, *Proceedings of the 2nd International ISCRAM Conference*, Brussels, Belgium.

Jiang, J., Li, YP., Huang, XL., et al. (2012) Lessons learnt from Wenchuan earthquake: Performance evaluation for treatment of critical injuries in extremely-hit areas After great earthquake, *Chin J Evid-based Med*, 5, 12, 504-511. (in Chinese)

Lu SB. (2008) Importance of classified treatment of the wounded in Wenchuan earthquake. *Med J Chin Peoples Liberation Army*, 33: 919. (in Chinese)

Mendonca, DJ., and Wallace, WA. (2007) A cognitive model of improvisation in emergency management, *IEEE Trans on Systems, Man, and Cybernetics-Part A (Systems & Humans)*, 4,37, 547-561.

Miao, CG., and Nie, GZ.(2004) Exploration on mode of earthquake emergency command, *J Nat Disasters*, 13:48-54.

Mors, A., Valk, J., and Witteveen, C. (2005) An event-based task framework for disaster planning and decision support, *Proceedings of the 2nd International ISCRAM Conference*, Brussels, Belgium.

Zhang, LL., Liu Y., Liu X., Zhang Y. (2012) Rescue efforts management and characteristics of casualties of the Wenchuan earthquake in China. *Emerg Med J*, 28:618-622.

Zhang, LL., Liu X., Li YP., et al. (2011) Emergency medical rescue efforts after a major earthquake: lessons from the 2008 Wenchuan earthquake. *The Lancet*, 3,379:853-861.

A Delphi approach for the establishment of the fundamental principles of an Organizational Security System in Public Administration

Victor A. Bañuls
Universidad Pablo de Olavide
vabansil@upo.es

Rafael Cantueso Burguillos
Junta de Andalucía
rafael.cantueso@juntadeandalucia.es

Fernando Tejedor Panchón
MSIG Smart Management
tejedor@msig.es

Miguel I. Ramirez de la Huerga
MSIG Smart Management
miguel.ramirez@msig.es

Murray Turoff
New Jersey Institute of Technology
Murray.turoff@gmail.com

ABSTRACT

The aim of this work is defining fundamental principles of an Internal Security System in the presence of intentional risks in Public Administration. The relevance of this object of study has increased even more with the emergence of new terrorist groups and the proliferation of organized crime, which have been categorized as a maximum threat to Security by the government. This context has led to new regulations and legislation on Security matters at the national and international level to protect assets, people and the activity of the Administration itself. Despite the large number of regulations and relevance of this topic, there is not any study which defines in a comprehensive manner the requirements that a security system must have in the presence of intentional risks in Public Administration. The results of this work are intended to be a reference for the Public Administration, for the prevention and reaction to damage to people, property, and operation, intentionally caused by external agents, personnel themselves or users. These principles have been applied and validated through a Delphi process in the Administration of the Regional Government of Andalusia in which more than 40 security-related managers have participated.

Keywords

Delphi, Public Administration, Intentional Risks, Homeland Security, Resilience.

INTRODUCTION

The Public Administration is characterized by a great diversity of buildings and facilities for which it is difficult to identify the competencies and responsibilities in terms of security. This is due to the fact that the management scope of security is usually distributed, meeting specialty criteria in the nature of the risks and the impact area, with a very varying degree of development and formalization (Smith and Brooks, 2013; Brooks, 2012). In this way, the scope of industrial risk prevention is generally found highly regulated (ISO 31000), as well as with

legally defined powers and responsibilities. Similarly, a varying degree of legal regulation is found within the scope of information security (ISO 27000), buildings and facilities protection against fire risks, intrusions, external aggression, or against natural events (NCSE-02), such as anti-seismic protection. Likewise, in recent years, the specific legislation has increased at an international level for critical infrastructures protection (Turoff et. al 2016). Most of the specific legislation, that regulates these security areas, is of general application from both the Public Administration and any natural or legal person, according to its scope of application and the definition of responsibilities

These circumstances provide a context for the risk management and the security within the scope of the Public Administration, characterized by (1) a great diversity of the institutional areas with competences concerning issues involved in security risks, (2) a varying degree of definition and development of the organization, powers and responsibilities for security risk management, and (3) a high degree of attractiveness to intentional threats. The Public Administration, like a city inside the city, can be understood as a set of interconnected dynamic systems (Godschalk, 2003).

In spite of the relevance of security within the Public Administration, and of the millionaire budget devoted to the protection of public buildings, there is no scheme that provides an integral global vision of the risks and security management, in all the areas and level within public administrations, and for all the types of risks and impact areas. This is due to the great diversity of existing approaches in the security and resiliency scopes, from different fields (Hernantes et. al, 2017). In order to contribute an initial approximation to this field, in this article, we propose the execution of the Delphi method for the establishment of design principles, and for the definition of the Internal Security Policy within the Public Administration for the reaction and prevention against damage to people, heritage and the operation, intentionally caused by external agents, personnel or users.

The present article takes the following form: In the second section, we will analyze the different types of risks and impact areas against damage, intentionally caused by external agents, personnel or users, to people, heritage or the normal operation within the Public Administration (occupational, infrastructure, heritage, information, aggressions, external risks…). In the third section, the execution of the Delphi method for the establishment of the Internal Security System within the Public Administration will be illustrated with a real case, that of the Andalusian Regional Government, Spain. Both the validation and results of the Delphi method are presented in the fourth section.

BACKGROUND

For the characterization of the actions currently carried out in the field of security, a classification has been used in the Scope of Protection, Type of Threat and Nature of Action dimensions.

Scope of Protection

The actions currently being carried out in the field of security are aimed at the protection of certain types of protectable properties, mainly as a result of the compliance with applicable regulations and legislation.

Protection against threats to the physical security of people and assets

It is the most traditional scope of security protection, aimed at preventing losses and damages in an organization, caused by people or groups whose objective is the appropriation of property, or causing damage to facilities, assets or people (Fisher et al, 2008). This area includes means and systems for prevention, containment, surveillance, detection and action against intrusion, such as perimeter fences, surveillance cameras, access controls, presence or movement detection system and alarm and response systems (ARC). If the risk is significant, it is common for this security function to fall to a specialized area in the organization. It is also common to have authorized external security and surveillance services to perform this function since in certain cases it is required by the legal requirements in the field of private security. In this field, specific national legislation has been developed, driven in recent years by the increase in the global terrorist threat, and including legislation derived from the European directives aimed at protecting critical infrastructures.

Protection against threats to workers' health

This area includes the management of risks to worker's health derived from the conditions and nature of their job: handling of toxic substances, handling of dangerous machinery, extreme environmental conditions, physical overexertion, etc... (ISO 45000). This function usually falls to the human resources area, which may have its own prevention and occupational health service or may have an authorized external prevention system. The methodologies for the evaluation and management of occupational risks are highly developed, and the methods and recommendations praised by the National Institute for Health and Safety at Work are regularly used as a reference.

There exists extensive legislation on occupational health, which establishes precisely the responsibilities and activities of organizations in this area. In this sense, it is compulsory that the organizations have an (own or external) occupational health officer, a Prevention Plan, and prevention service. Legislation and technical standards also cover the scope of protective equipment applicable to each activity. Management standards have also been developed in this area, as well as voluntary certification schemes.

Protection against industrial threats to the personnel, population, and environment

Industrial accidents (fires, explosions, spills, toxic clouds …) have historically caused huge damage at personnel themselves in the facilities, in the environment, and in the surrounding populations. The risk management in this area is aimed at preventing the occurrence of these accidents or minimizing the damage caused (ISO 31000). There exists national legislation in this area which requires the organizations with certain characteristics to have Emergency Plans to respond to possible emergencies. These plans should define the responsibilities for the response to incidents and coordination with external intervention services (firefighters, civil protection, police officers), as well as self-protection actions (evacuation, confinement, threat containment …). The legislation also develops European directives (SEVESO) aimed at protecting the populations against the threat of major accidents. The field of industrial Security also includes the legislation and technical standards applicable to certain equipment and machinery (pressure devices, lifts, fire extinguishers …) which require its certification and periodic verification.

Protection against threats to information security

The development and widespread of the use of communication and information technologies (ICT) in recent times has led to a parallel increase in the volume and sophistication of threats for the integrity of sensitive information for individuals and organizations. Cybersecurity is the practice for the protection of the information and ICT systems against intrusions (hackers) and harmful programs (viruses and malware). It has also been developed management standards in the field of information security and voluntary certification schemes (ISO 27000; ISO 14000).

Protection against threats to essential services for the population

Essential services for the population such as drinking water supply, sanitation, transports or energy supply are subjected to increasing global threats (terrorism, geopolitical tensions…) in an increasingly independent context. In recent years, European and national legislation has been developed for the protection of critical infrastructures which provide these essential services. This legislation establishes responsibilities and mechanisms of analysis, planning, and response to mitigate the risk for these infrastructures, to protect them against threats and to respond to possible incidents which may occur. At the voluntary level, technical standards and certification schemes have been developed for global risk management and its business continuity (ISO 22301; ISO 22320).

Protection against criminal threats

In recent years, the treatment of other types of threats have been formalized such as those which affect the criminal risk of the organizations and workers (compliance) (ISO 19600). National legislation has been developed in this field, as well as international compliance management standards. It is necessary to consider that risks interact with each other so that a criminal risk for workers can become a risk for the continuity of the activity if they limit their

actions to avoid criminal risk. As it is mentioned in the table, the basic regulations may cover more than the protection area.

Type of threat

United Nations Disaster Relief Organization (UNDRO) classifies risks into those caused by natural, human or technological threats:

- Natural: risks of which triggering is not directly caused by human presence or activity, but by climatic and geological factors.
- Human: risks caused or derived from human activities and actions.
- Technological: human risks which derive from technological development and significative use and application of technologies.

On the other hand, public preparedness is considered to be important in the fight against terrorism. So, homeland security needs to give special consideration to threats of intentional origin in Public Administration. Considering the foregoing, the actions in the security area Public Administration could characterized by the criteria of responding to an accidental threat, or an intentional threat, as described in table 1.

Table 1. Types of threat

Type of threat	Description
Accidental	The technological, human and natural threat, of which occurrence is not caused by the intention of groups or individuals to cause damage to protected property.
Intentional	The technological, human and natural threat, of which occurrence is caused by the certain intention of groups or individuals to cause to damage to protected property.

Areas of protection

Security management has also developed in its approach, from its purely instrumental initial conception, in which the organizations provide reactively, ad hoc and isolated responses to emerging security needs. Currently, it is necessary a proactive and systematic approach, with a strategic intention based on the understanding of the context and necessities of stakeholder and using a formalized management system as a tool for developing such strategy. A management system is a group of elements within an organization, which are interrelated or interact to establish policies and objectives, as well as processes to achieve those objectives. Standardized Security Management System models are currently available in various protected areas (Table 2).

Table 2. Standardized Security Management Systems in Protection Area

Model	Area of protection	Type
ISO 45001 Occupational health and safety	Security and health of the workers. It substitutes OHSAS 18001 Standard	Accidental
ISO 22301 Business continuity management	Continuity of essential services	Accidental Intentional
ISO 22320 Social Security. Emergency management	Security and health of the workers Security and health of citizens	Accidental Intentional
ISO 31000 Risk management	A comprehensive model for risk management and incident response in all areas of protection	Accidental Intentional
ISO 55001 Assets management	Model for the asset life cycle management, including its conservation and maintenance	Accidental
ISO34001 Security management system	Protection against internal or external fraud. It is developing	Intentional
ISO 14001 Environmental management systems	Protection of the environmental estate	Accidental
ISO 19600 Compliance management systems	Protection of legal compliance	Accidental Intentional

CASE STUDY

In this case study, the design process of a Comprehensive Risk Management and Security System within the scope of the Regional Government of Andalusia, for comprehensive management of the different types of risks. This system is based on an institutional architecture, a governance system, and the definition of competencies and responsibilities for policy coordination, objectives, strategies and actions in terms of security amongst various government agencies, as well as amongst various operators with competences concerning any risk management area and the security of the Regional Government of Andalusia.

Context

Regional Government of Andalusia is the institution in which the self-government of the Autonomous Spanish Community of Andalusia is organized. It is integrated by the Parliament of Andalusia, the presidency of the "Junta de Andalucía" and the Governing Council. The 2019 budget amount to 34,759 million euros, and it has more than 270,000 direct employees.

Methodology

The research methodology on which this work consists of three sequential phases (Figure 1).

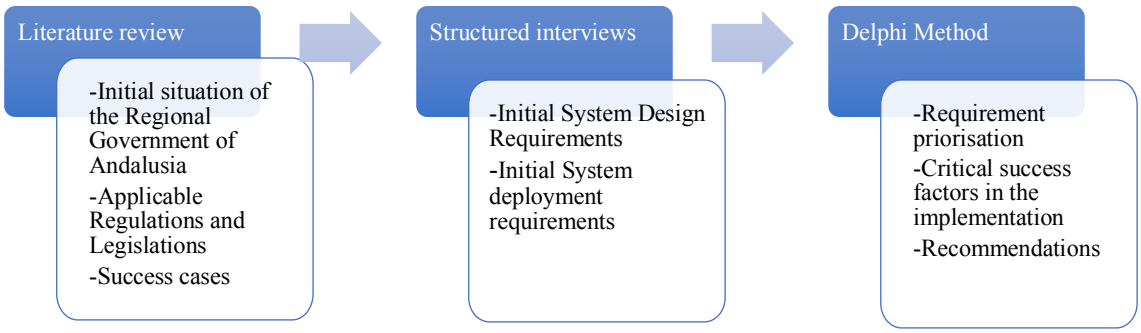


Figure 1. Methodology

The first stage is based on a review of the literature to characterize the initial situation of the security organization in the Regional Government of Andalusia, the main applicable regulations and analysis of success cases and reference of security management at national and international level. In addition, an analysis of the estate inventory has been performed, considering all Central Administrations and Agencies (excluding commercial companies) to define the scope of assets to be protected. As part of this stage, a model of approach to the Internal Security in Public Administration has been proposed, since we have not found in the literature a single approach that allows us to classify the activities at the level of security that is carried out in a Public Administration of the size of the Regional Government of Andalusia. In addition, a glossary of security terms has been compiled. This glossary is based on the main national and international standards, regulations, and legislation.

In the second stage, a series of personal interviews were carried out with 9 interlocutors with responsibilities in different areas of protection in the Regional Government of Andalusia. In these interviews, a wide variety of issues have been posed in order to characterize the current security situation in the Regional Government of Andalusia. This methodology is useful as a means of providing input for an initial approximation of design and implementation requirements of the Andalusian Regional Government's Internal Security System.

In the third stage, the conclusions obtained both from the literature and from the personalized interviews using the Delphi Method were compared. Delphi method is an analytical technique based on the judgment of a group of experts. It consists of an iterative and systematic process aimed at obtaining the opinions, and if possible consensus, of this group of experts. Its main characteristics include anonymity, controlled repetition and statistical treatment of responses. The Delphi method was developed in the Rand Corporation during the 50s (Helmer and Rescher, 1959). This technique was designed to develop a debate independent of personalities. The Delphi method is based on anonymous communication with feedback. Anonymity is required in the sense that no one knows who else is participating. Moreover, judgments are summarized and sent back to the group for further analysis in the form of sequential questionnaires. Processing data in this way help to minimize psychological effects and time demanded in comparison with another group (Linstone and Turoff, 1975; 2002). With the profound impact of the internet on organizational and community planning systems, Delphi it will foster a new age of participation through communication, coordination, and collaboration (Linstone and Turoff, 2010).

Field Work

32 experts have participated in the Delphi process, among all of them there are people responsible and key actors in the future of Internal Security System of the Andalusian Regional Government, such as Technical General Secretariat (TGS) of several Ministries, General Secretariat (GS) of Several Government Delegations, as well as Directorates-General and equivalent departments of key areas for the security field and experts in the field from other Agencies and Directorates-General of the Regional Government of Andalusia. Delphi study had a response rate of 60.37%, which means high participation in the study.

Following the Delphi Methodology, each expert was given a set of principles resulting from the provisional conclusions of the initial study. In addition, a series of open-ended questions were included in which could contribute to relevant aspects not covered in this first round of the Delphi process. In a second round, each expert was given both their response and the group's response so that they could make a comparison and make comments and assessments if they deemed it appropriate. The comments of the entire panel of experts were sent to other participants anonymously so that the rest of the group could establish the degree of agreement on further contributions from the panel of experts.

RESULTS

Design Principles

A first result of the study in the need to establish a Basic Security Management Model for the future Internal Security System for the management of risks caused by international threats of the Regional Government of Andalusia with the following components:

- Security Policy: The definition of the scope of protection, and of overall objectives, principles, and commitment in the security area.
- Government framework: Organization and responsibilities for the definition and deployment of security objects, coordination of actions for risk treatment and analysis, and for the assessment, review, and updating of the security management system.
- "Typological" Analysis of Risk: Identification of the types of threats to the protection area, and "standard methods" for the assessment of the risk associated with the impact and probability of occurrence of the threats.
- Risk treatment: Establishment of criteria and strategies for the treatment of risks, and implementation of the necessary security and protection measures to migrate the risk to an acceptable level.
- Response to incidents: Definition of responsibilities for the identification, notification, and classification of incidents, as well as for the activation and coordination of action plans to respond to the incident.
- Monitoring, Assessment, and Improvement: Monitoring of indicators, security management system audit, and incident response drills, as well as an assessment of the response to an incident that has occurred, they provide information on the effectiveness of the security management system and possible opportunities of improvement.

In a complex organization, as it is the Regional Government of Andalusia, this Base Model may require a Government Framework and deployment according to the different levels and organizational structures. Additionally, the development of the tools for the promotion of Safety Culture in the Regional Government of Andalusia has been established as a priority as a fundamental pillar of the system. Culture is an intangible force behind the measurable and observable that moves an organization to action. Due to the organizational culture has such a profound effect and the behavior of individuals, it should be understood and managed to achieve the desired objectives. The lack of Safety Culture may involve structural risks that are difficult to address. Therefore, any Security System to be promoted by the Regional Government of Andalusia must be rooted in the promotion of the Safety Culture among workers and users of the services.

Other relevant but less important aspects for the panel of experts are:

- Centralization of information: There exists a need to centralize and coordinate information and communications in a complex structure such as de Regional Government of Andalusia in the field of security.
- Resilience: A resilient organization must have the ability to ability to anticipate disruptions, adapt to events

and create lasting value. A resilient system involves the ability to absorb disturbances, respond efficiently and recover from unexpected events. In this sense, the Security System of the Regional Government of Andalusia to be resilient should have the attributes of robustness, redundancyand speed.

- Change management: The success of the implementation of the Security System in the Regional Government of Andalusia also depends on proper management of the possible resistance of a new System, making it easier for the organization itself to accept, support and effectively manage the change.

Keys of implementation

As a result of the Delphi process, the experts on the panel have provided their views on the key aspects of the implementation of each of the Internal Security System's design principles, which we summarize below:

Security Policy, Government Framework, and Management

The experts stress the need to define a Security Policy, including the Management and Government Framework, relevant areas and departments. It is outlined the need to include coordination mechanisms with other existing systems as well as with the national and international security forces. According to the panel, it is essential to consider the particularities of each of administration's activities, especially those with a higher concentration of risks.

According to the participants, the design of the Security Policy must consider all employees and positions of the Regional Government of Andalusia, considering this difference in profiles and responsibilities so that each one can apply the protection mechanisms that are relevant to them. It should also include mechanisms for monitoring, assessment and information management at all levels. The training of those responsible for Security matters is a critical aspect for the success of the implementation as well as the awareness and involvement of workers and users of the services of the Regional Government of Andalusia.

Protection area, Analysis and Risk Treatment

The result of the Delphi process indicates that the threat catalogs need to specifically address the situations of greatest risk exposure. They also count on the contribution of the knowledge of personnel at all levels of the Administration, making catalogs of threats against the administrative structure (services, sections, and negotiations), as well as against the holders of managerial posts in the Regional Government of Andalusia, according to their rank and competences.

According to the panel of experts, the Internal Security System should have communication and dissemination mechanisms that are as broad, complete and close as possible in order to make publish both the catalog of risks that an employee/site faces and the prevention and treatment mechanisms that are applicable. Technical advice on security matters should also be provided on a permanent basis to the institutions.

Responses to Incidents, monitoring, improvement:

The results of the Delphi panel show that, at the level of Incident Response, it is key the specific training of personnel (managers, coordinators, etc.), with special emphasis on those who carry out their activities in centers with high levels of risk. On the other hand, it is outlined the need to perform the Monitoring and Improvement of management indicator implementation in the field of Safety.

It would be essential to establish coordination measures by the Regional Government of Andalusia, but always considering specificities and characteristics of each area, drawing up procedures jointly between the Ministries with competence in the field of Security. In addition, the National Police Unit attached to the Autonomous Community of Andalusia should be involved in the analysis, monitoring, and improvement.

Security culture

Regarding Security Culture, the panel of experts' stresses that the training and awareness in Security are essential to avoid incidents, and also allows for a better reaction in the event of an incident.

For this, it is necessary to involve workers and users, creating Culture but without generating an atmosphere of fear. Such training should begin with that of the management staff of the Ministries and Delegations of the Government and Territorial Delegations.

In order to achieve a greater involvement and awareness by managers, public employees and users, in the opinion

of the panel of experts, it is necessary to improve horizontal and transversal communication channels in the area of security, especially with regard to new recruits who are responsible for safety or who are in charge of buildings or people subjected to relevant risks.

Other key implementations

Regarding the Centralization of Information, the panel proposes to promote the existence of a fluent information channel for those responsible for the different centers, reinforcing and guaranteeing the upward and downward channeling of information. This issue would require common information tools and standardized communication processes.

Regarding the provision of Resilience to the International Security System, the experts indicate that it would be important to guarantee the availability of means and resources in the area of Security, as well as the flexibility and adaptation of the System to the characteristics of each asset, since the risks and implications of these differ according to the context. They also propose the development of tools to analyze unforeseen situations that have caused damage, collecting the appropriate conclusions to prevent or minimize them as far as possible. Resiliency is too often measured against prior natural disasters and climate change is increasing the level of damages above past values so that by replacing what was there and damaged without increasing the resistance/survivability to larger natural disasters is a major decrease in resiliency (Turoff et al., 2018).

Finally, the experts point out that a large part of the success in the implementation of the Internal Security System lies in an adequate Management of Change, whose pillars would be the involvement of the management, awareness campaigns among public employees and users and the training of personnel.

Through adequate communication, the new International Security System should be presented as something positive and not as a new workload and responsibilities, reflecting the need for its proper development and the benefits of its implementation.

Model base

The conclusions of the panel of experts firstly highlight – with a level of agreement of 4.71 on the scale of 5, where 5 suppose "total agreement" – the need to establish a global governance framework and management of security in the face of international risks at the level of the Regional Government of Andalusia. This government framework should allow for the definition and effective and coordinated deployment of comprehensive security policies, as well as those established in each specific area of protection. As we mentioned in the methodological section, this panel of experts have key actors and responsible people in the future of Internal Security System of the Regional Government of Andalusia such as SGT of various Ministries, GS of some Government Delegations as well as Directorates-General and equivalent departments of key areas for the field of security and experts in the field from other Agencies and Directorates-General of the Regional Government of Andalusia.

A series of principles are also established for the design of an Internal Security System in the event of international threats to the Regional Government of Andalusia. A first element to be included in the design is the establishment of a Base Model for the Management of Internal Security which elements and interrelations are expressed in figure 2.

Some key properties to include in the design of the System for the correct functioning of this Base Model would be the Security Culture, the Centralization of Information, the work for Resilience and a Change Management design.

At the implementation level, key factors are considered:

- Coordination with other existing systems and at different levels of management.
- Management commitment.
- Communication with everyone involved in the system.
- Awareness-raising at all levels, including users.
- Training as a key to promoting a Culture of Security and Change Management.

In this sense, the panel of experts stress that the processes of design and implementation of the new Internal Security System must consider developments in the field, requiring the active participation of the various Ministries, Management Centers, and Entities of the Andalusian Regional Government, through the appointment of their heads or coordinators. It is essential to be able to transmit the advantages and benefit of the new System, as well as to plan the required resources for launching it and establish a well-defined roadmap for its implementation.

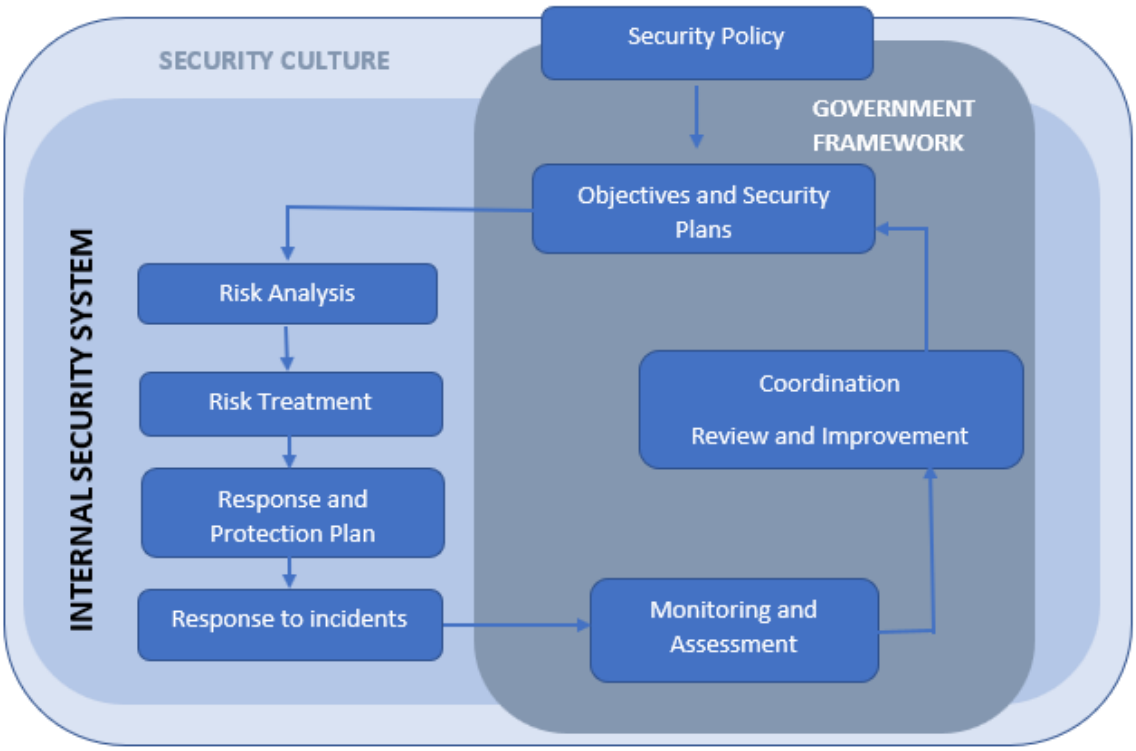


Figure 2. The relationship among elements of the Base Model for Security Management

It is also necessary the communication and the training at all levels un matters of safety, fundamentally regarding the rights and obligations derived from own and third parties' actions in the use of material elements and the use of public buildings.

CONCLUSIONS

In this article, a Delphi approach has been proposed for the establishment of design principles of a Comprehensive Risk Management and Security System in a large Public Administration. With this system, we have aimed to provide a global approach to carry out planning, prevention, protection, reaction, assessment and improvement activities, as well as the coordination amongst the various kinds of agents involved in terms of security against international threats.

One early conclusion is the transversal nature of the security within the Public Administration. This matter makes the integration and identification of a Comprehensive Risk Management and Security System with other possible high-level shortcomings within the organization with competences concerning security, respecting the identity of the rest of the systems despite defining coordination mechanisms amongst one of them, be one of the main challenges when it comes to developing a Comprehensive Risk Management and Security System

A second conclusion is the adequacy of the Delphi method to define a Comprehensive Risk Management and Security System. As it has been stated before, these systems have various kinds of ramifications and interactions with all the Public Administration structure. Due to the suitability of the Delphi method for dynamic planning in episodes of high uncertainty, this technique has shown itself to be added value in the process by the Administration for its execution. The best indication is that, based on the established principles, the regulatory support for the assurance of the governance of the Comprehensive Risk Management and Security System in a Public Administration has been developed.

ACKNOWLEDGMENTS

We want to express our gratitude to the authorities and officials of the Administration of the Junta de Andalucía who, always interested in the continuous improvement of the facilities' security, have collaborated in this research.

REFERENCES

Brooks, D.J., 2012. Corporate security: Using knowledge construction to define a practising body of knowledge. *Asian Journal of Criminology,* http://dx.doi.org/10.1007/s11417-012-9135-1.

Fischer, R.J., Halibozek, E., Green, G., 2008. Introduction to Security, eighth ed. Butterworth-Heinemann, Boston.

Godschalk, D. R. (2003). Urban Hazard Mitigation: Creating Resilient Cities. Natural Hazards Review, 4(3), 136–143. https://doi.org/10.1061/(ASCE)1527-6988(2003)4:3(136).

Helmer, O., and Rescher, N. (1959). On the epistemology of the inexact sciences. *Management Science*, 6(1), 25–52.

Hernantes, J., Labaka, L., Turoff, M., Hiltz, S.R., Bañuls, V.A. (2017) Moving forward to disaster resilience: Perspectives on increasing resilience for future disasters. *Technological Forecasting and Social Change*, 121, pp. 1-6.

ISO 14001: Environmental management systems. https://www.iso.org/iso-14001-environmental-management.html.

ISO 19600: Compliance management systems. https://www.iso.org/standard/62342.html.

ISO 22301: Business continuity management. https://www.iso.org/standard/50038.html.

ISO 22320: Social Security. Emergency management. https://www.iso.org/obp/ui/#iso:std:iso:22320:ed-2:v1:en.

ISO 27000: Information security management system. https://www.iso.org/obp/ui/#iso:std:iso-iec:27001:ed-2:v1:en.

ISO 31000: Risk management. https://www.iso.org/iso-31000-risk-management.html.

ISO 34001: Security management system. https://www.iso.org/obp/ui/#!iso:std:61588:en

ISO 45001: Occupational health and safety. https://www.iso.org/iso-45001-occupational-health-and-safety.html

ISO 55001: Assets management. https://www.iso.org/standard/55089.htm

Linstone, H.A., and Turoff, M. (Eds.), The Delphi method: techniques and applications, Addison-Wesley, Reading, Mass, 1975. (Available online at http://is.njit.edu/turoff).

Linstone, H.A. and Turoff, M. (2011) Delphi: A brief look backward and forward, *Technological Forecasting and Social Change*, 78 (9), pp. 1712-1719.

Real Decreto 997/2002, de 27 de septiembre, por el que se aprueba la norma de construcción sismorresistente: parte general y edificación (NCSR-02).

Smith, C. L., & Brooks, D. J. (2013). Security Science: the theory and practice of security. Butterworth-Heinemann, Boston [978-0123944368].

Turoff, M. Bañuls, V. Ramírez de la Huerga, M. (2018) Hurricanes Send Signals for the Future of Emergency Preparedness. *Proceedings of the ISCRAM 2018 Conference*, Rochester, US.

Turoff, M., Bañuls, V., Hiltz, S.R., Plotnick, L., and Ramírez de la Huerga, M. (2016) A Collaborative Dynamic Scenario Model for the Interaction of Critical Infrastructures. *Futures*, Volume 84, Part A, November, Pages 23–42.

Towards an organization certified in emergency plans management

Ana-Gabriela Núñez
ISSI-DSIC
Universitat Politècnica de València, Spain
anunez@dsic.upv.es
Universidad Nacional de Educación, Ecuador
gabriela.nunez@alttics.com

Ma Carmen Penadés
ISSI-DSIC
Universitat Politècnica de València, Spain
mpenades@dsic.upv.es

ABSTRACT

QuEP is a framework that guides organizations in assessing and improving their emergency plan management by following a set of principles, practices, and techniques at the different maturity levels established in the *QuEP* model. Its main objective is to be applied to real cases to discover the state of an organization's emergency plan management and recommend techniques for improvement. In this paper, we describe the first application of *QuEP* as a prior step to its implementation and possible use in official certifications for emergency plans with a guarantee of quality. So, we have applied a real case in a UPV building towards the certification of the emergency plan management.

Keywords

Emergency Plans Management, Total Quality Management, Maturity Levels, Techniques, Certification

INTRODUCTION

Organizations' efforts to instill continuous improvement is related to the ability to deliver products and services to customers with a quality mark. Organizations in different areas need to guarantee their products and services according to international quality standards. Certification gets a formal document to certifies that a product, system or person complies with guidelines established in a given standard, which has a period of validity. A certification must be objective, reliable and accepted by all interested parties.

The quality assurance approach is reinforced by a third-party certification system, where an independent, specialized and duly accredited organization certifies through an audit based on predefined quality standards; or homologate a product proving that it meets the technical. The confidence of certification by third-party is superior to the first-part certification or internal evaluation, or the second-part certification or carried out by another organization since the certifying is impartial (Camisón et al. 2007). The value of this certificate rests on the prestige or quality mark. Among the standard commonly accepted in the international scope like ISO. In fact, ISO9000 certification and Total Quality Management (TQM) practices directly affect organizational performance.

The ISO 9000 family contains some of the best-known ISO standards, which cover different aspects of quality management (D. Singhal and K. Singhal 2008). For example, ISO/IEC90003, which deals with software engineering, ISO31000 with risk management principles and guidelines, ISO14001 with similar environmental management systems-requirements, with guidance for the use of, among others (ISO 2016). Furthermore, the ISO 22320, is an international standard for Emergency Management Systems and Incident Response that allows organizations to develop and improve their response capabilities (ISO 2011).

On the other hand, as TQM implementation focuses on the criteria for a quality award, it allows some organizations to use this approach which can result in improvement based on relevant TQM models. For example, the Deming Prize (JUSE 2014), the European Quality Award (EFQM 2014), or the Malcolm Baldrige National Quality Award (Baldrige 2014), among others. A certification or Seal of Excellence shows that an organization is profitable while guaranteeing a high level of quality products or services. However, there is no certification for organizations with proper emergency plans management.

QuEP has been presented as a framework inspired by TQM to assess and improve emergency plan management in organizations (Núñez et al. 2016b). Currently, *QuEP* has a model supported by a web application, which is the *QuEP-Tool v1.0*. Applying *QuEP* to real cases is vital to determine the current state of an organization regarding its emergency plan management and what techniques it should consider for continuous improvement in its activities. Consequently, the goal is to gain skills in all the activities performed by the stakeholders before, during and after the emergency plan management. This paper describes a work in progress of how *QuEP* can be used to certify emergency plans and their subsequent maintenance as a certification by third-party.

This paper is organized as follows: Section 2 describes the emergency plan life cycle and how *QuEP* is integrated to support the certification subprocess. Section 3 describes a case study in which we assessed an organization as a pilot test for certification. Section 4 concludes the paper and outlines further work.

THE EMERGENCY PLAN LIFE CYCLE

The emergency plan follows a series of steps from the preparation, implementation and continuous maintenance, as indicated by regulations or laws such as: the "Self-protection Law" (NBA 2007) in Spain, the "Comprehensive Preparedness Guide" (CPG) 101, published by the Federal Emergency Management Agency (FEMA) (CPG101 2010) in USA, the United Kingdom's "Guidance-Emergency preparedness" (UK-gov 2013), among others.

The general process that we inferred from the regulations is shown in Figure 1, where the first step in preparing the emergency plan focuses on how the organization must follow the regulations. The second step is related to the implementation of the emergency plan, in which the organization must train staff, establish public information mechanisms, and provide resources for the application of the emergency plan. The next step is related to the certification that would allow organizations to prepare and implement better emergency plans. The last step is the maintenance and continuous improvement of the emergency plan that involves activities such as: following a continuous successive and interactive preparation process, conducting training activities, conducting emergency drills, and evaluating the emergency plan, taking into account that the emergency plan evaluation should cover a maximum period of three years.

The certifying process requires to ensure compliance with the norm through steps such as if the organization complies with the requirements defined according to local regulations, through an assessment model or approval accrediting that the organization follows certain technical specifications carried out in the different activities of the emergency plan management. Although the public administration approves regulations and laws, receives and approve the emergency plans proposed by organizations, there is a lack in the life cycle of these activities in the preparation, implantation, and maintenance of the emergency plan, which is related to the fact that there is no certification that provides adequate support for this. The weak point in this work is that in many cases organizations register their emergency plans based on current laws, but much more remains to be done, and the public administration does not provide an adequate follow-up to each step. *QuEP* supports certain activities of the emergency plan life cycle, as shown in Figure 1 by the dashed red line.

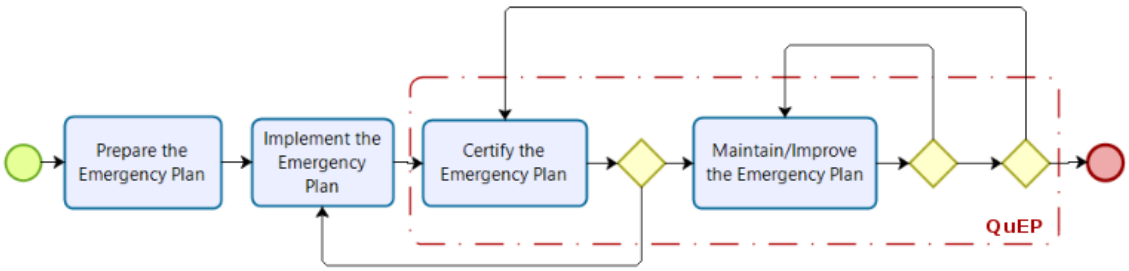


Figure 1. The Emergency Plan Life Cycle

The QuEP framework

QuEP (Quality of Emergency Plans Management) is a framework for the assessment and improvement of emergency plan management within organizations (Núñez et al. 2015). The *QuEP* framework is based on the study of quality aspects of a good emergency plan (Berke and Godschalk 2009). *QuEP* assesses the planning process and analyzes the capabilities of the participants, and all the activities carried out before, during and after the process of implementing the emergency plan. Firstly, the *QuEP* core is defined by maturity levels, which can be seen both as evaluation criteria and as a roadmap for the improvement of the different activities or practices carried out

(shown in Figure 2(a)). The *QuEP* model is then defined (shown in Figure 2(b) with a UML class diagram); this is the basis of our assessment model that is based on principles, practices and techniques (Dean and Bowen 1994). Dimensions are established that define the activities or practices that will be discussed in each of the principles and their corresponding maturity level, and finally, questionnaires formed by questions that are provided to the corresponding stakeholders by role (shown in Figure 2(b)).

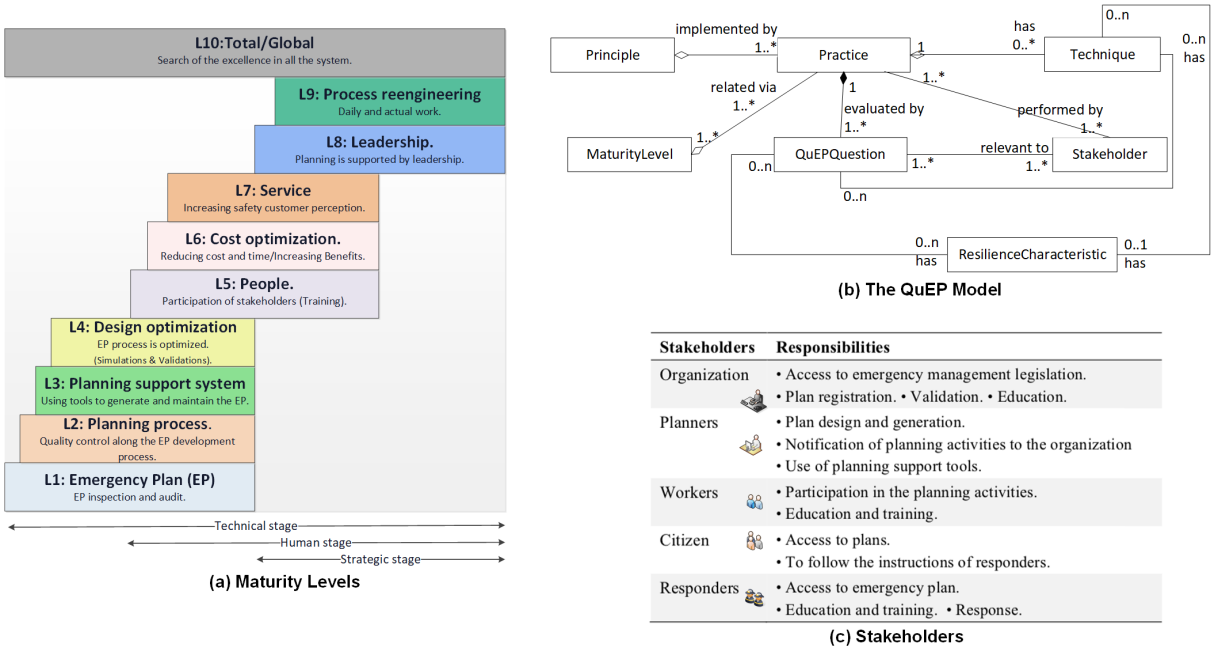


Figure 2. Maturity Levels and QuEP Model extracted from Núñez et al. 2016

Ten levels of maturity are defined in *QuEP*, from level 1 (L1: Emergency Plan) to level 10 (L10: GCT (Global/Total)). These levels are grouped into three stages: the technical stage, the human stage, and the strategic stage, following the approach proposed in Camison (Camisón 1998). Each of the levels associated with each stage is seen as the steps of a ladder that every organization committed to the search for quality improvement in the management of its emergency plan should try to climb.

QuEP principles are intended to guide the organization in the management of quality regarding emergency plans and planning processes, including the actions of all its stakeholders involved in emergency plan management activities (shown in Figure 2(c)). In *QuEP*, nine principles have been identified, including *Risk-Driven (A)*, *Implementation (B)*, *Participation (C)*, *Monitoring (D)*, *Cooperation (E)*, *Safety People (F)*, *Leadership and Policies (G)*, *Results of objectives (H)*, and *IT & Innovation (I)*. The practices are activities that facilitate the application of the principles of the QuEP framework and lead to the organization complying with them in the emergency plan management. The principles are implemented through practices that are carried out by all stakeholders in the organization. In *QuEP*, twenty-seven practices have been identified grouped by principle. For instance, practices such as *emergency drills*, *resource improvement and maintenance*, *process improvement*, and *process for updated emergency plan* concern to *Monitoring (D)* principle. The techniques provide the organization with the knowledge of what should be done to apply the best practices in the emergency plan management. A set of guidelines and recommendations associated with each of the practices was identified to identify the techniques, obtained from different guidelines, regulations or laws available in some countries. The resilience characteristics can be associated with questions and techniques as complementary practices and the coordination of multiple stakeholders working towards more resilient organizations.

Assessment of the *QuEP* framework by experts in planning and risk management is essential to validate its viability for evaluating emergency plan management (Núñez et al. 2016b). The results obtained from the *QuEP* questionnaires given to the stakeholders of an organization facilitate and automate the assessment of an organization and generate the appropriate improvement reports to identify the best practices through the support tool *QuEP-tool* (Núñez et al. 2016a). Results are presented to know the minimum requirements of an emergency plan management at each maturity level as acceptable or tolerable. Currently, the limit or threshold value μ=0,5 have defined from beforehand. Also, QuEP considers if a question has more weight than others. It means, there are questions more relevant.

Before certifying the emergency plan management first step is to perform tests in real organizations. A pilot assessment is essential to ensure that the *QuEP* model is adequate, viable and competitive in organizations under public administration regulations.

CERTIFICATION PROCESS

Our proposal for certification in organizations with *QuEP* follows a process, where the first step is the *preparation* that includes the selection of the organization and the stakeholders involved. Next step is related to the *QuEP application* in the assessed organization. The last step is the *reports presentation* to the organization related to its management of the emergency plan and the aspects that must be considered to achieve continuous improvement in its current and future activities.

Preparation

For the pilot assessment, we have selected as organization the 1F-UPV building at the UPV, and 25 *stakeholders* have participated based on roles defined in *QuEP*. In this context, we contacted the person responsible person for the emergency plan in building 1F, who participated in the organization role (Org.). A person responsible for planning and accident prevention in the UPV played the planner role (Pla.). Fifteen other people were selected for worker roles (Wrk.), of which seven were Master students, two professors, and six Ph.D. candidates in Computer Science. Eight people who had accessed the 1F building at least once participated in citizen roles (Cit.). The assessment of the responder role (Rsp.) was omitted, since no emergency drills had been held in the 1F-UPV building since 2011.

QuEP application

We have developed *QuEP-Tool v1.0* to carry out the application of *QuEP* in the 1F-UPV building. This tool support to apply *QuEP* and later get the results. In order to assess an organization *QuEP* uses questionnaires[1] according to principles and their associated practices, and a set of questions defined to assess the degree of compliance with each *QuEP* practice. Different techniques have defined to help the organization improve its practices and, as a consequence, to increase their maturity level.

To the 1F-UPV building assessment, only two of the nine principles have been assessed: the *Risk-Driven (A)* principle and the *Monitoring (D)* principle. The first step was to make visible the information and guides about the 1F-UPV building assessment through *QuEP* portal[2] protected by a password. The stakeholders who participated in this assessment were given a user password via email. The next step was to make the assessment, between April 23 and June 1, 2018. The research team then analyzed the results.

Reports presentation

The maturity levels obtained for the 1F-UPV building are shown in Figure 3. The organization reached a global maturity percentage of 54.8%, which we consider as tolerable although capable of improvement. For the certification of the emergency plan management, the tolerance should be considered at each level, defined in advance through a limit or threshold value. If we assume that it is 50%, this organization would be certified, but with a list of improvements to be made. The advantage of QuEP is that it also breaks down the results into levels, which allows a much more detailed analysis.

100% results were obtained at levels 3 and 6, since the answers to the questions for the organization holder and planner roles obtained the highest value. At level 7 most *stakeholders* responded that they did not know if the organization announced the programming of the emergency drills or if an analysis and report had been carried out after an emergency drill. Something similar happened at level 9, the vast majority were not aware of whether for example, the organization prepared periodic reports of emergencies (emergency drills, and incidents, among others) or if security inspections had to be registered.

Analysis by groups

The results divided into four groups for analysis. The first group (GRP-1, 17 *stakeholders*), consists of the results obtained from the planner (Pla.), organization holder (Org.) and workers (Wrk.), without considering the citizens (Cit.). The second group (GRP-2, 5 *stakeholders*) was made up of the results of the planner (Pla.), organization holder (Org.) and the workers (Wrk.) with experience in emergency plan management (two professors and one

[1] https://quep.webs.upv.es/quep-questionnaires/
[2] 1F-UPV building: https://quep.webs.upv.es/es/evaluacion- del- edificio- 1f/

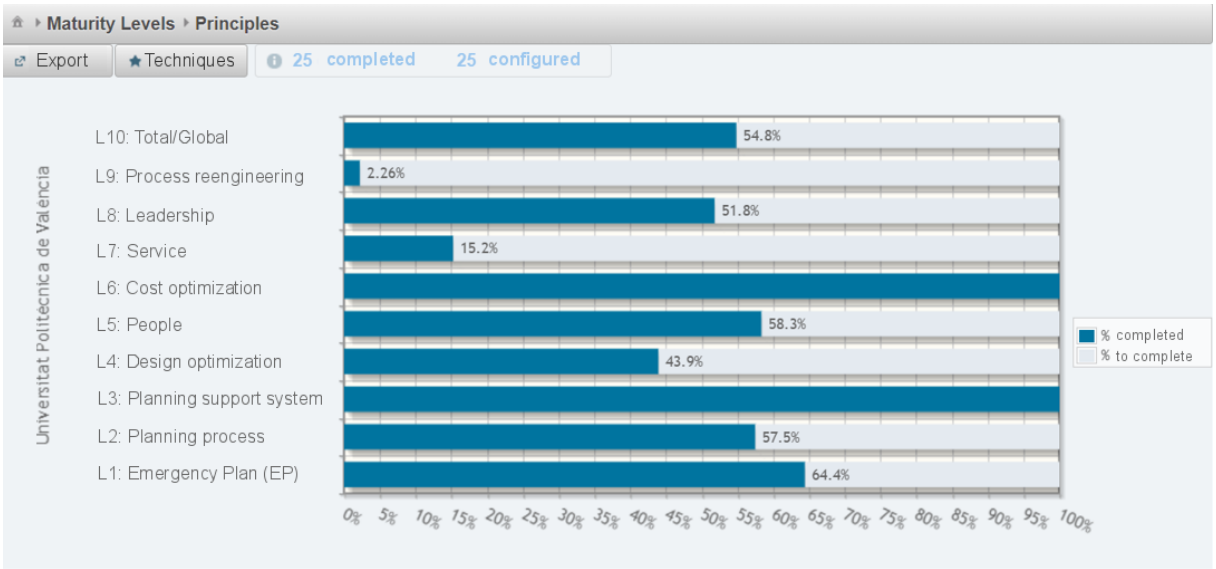


Figure 3. Results of the 1F-UPV building by *maturity levels*

Ph.D. student). The third group (GRP-3, 2 *stakeholders*) consisted of the results of the planner (Pla.) and the organization (Org.). The fourth group (GRP-4, 1 *stakeholders*) consisted only of the results of the planner (Pla.).

The results by stakeholder groups are shown in Table 1. The maturity percentage obtained at level 10 was 54.8% and in GRP-1 was 54.7%, which dropped by 1% because some citizens had more training in academic institutions than some Ph.D. students, who lacked information. In the following groups, we can see that the percentage increases as the groups are made up of participants who are aware of the management of emergency plans. In fact, the planner has the most information of the whole process of drawing up, implementing and maintenance of the emergency plan.

Table 1. Results by group

	All (25)	*GRP-1 (17)*	*GRP-2 (5)*	*GRP-3 (2)*	*GRP-4 (1)*
Global/Total (Level 10)	54.8%	54.7%	61.8%	66.8%	74.6%
Risk Driven Principle (A)	72%	71.1%	76.6%	77%	87.2%
Monitoring Principle (D)	43.2%	44%	49.5%	50.6%	67.3%

Although the score obtained from the planner results (GRP-4) is 74.6% excellent, we were interested in the planning process to disseminate the necessary information at all levels, so that the different *stakeholders* could have access to information and be trained in accident prevention. The results obtained by principles show that risk management is much better than monitoring in all the groups. The percentages obtained in the evaluation of the 1F-UPV building with the *stakeholders*' GRP3 and GRP4 responses were higher than those of the responses of all the *stakeholders*, since the planner and the organization holder have more knowledge than the workers and citizens.

Recommended techniques

Figure 4 shows an example of techniques or best practices that should be considered in the 1F-UPV building to increase the quality of the planner assessment in the emergency plan management (GRP-4), grouped by maturity levels. Only eight techniques are shown spread over three maturity levels, but the techniques increase as the stakeholder assessment is included.

Other aspects and recommendations

The results obtained in the 1F-UPV building gave us an overall view of its emergency plan management and the best practices that could be improved. In general, while 50% of the emergency plan management in this building is tolerable or acceptable, 45.2% of the activities need to be improved. This shows that the *QuEP* certification framework is viable, and can help organizations to improve their emergency plan management by looking at what can be improved and updated.

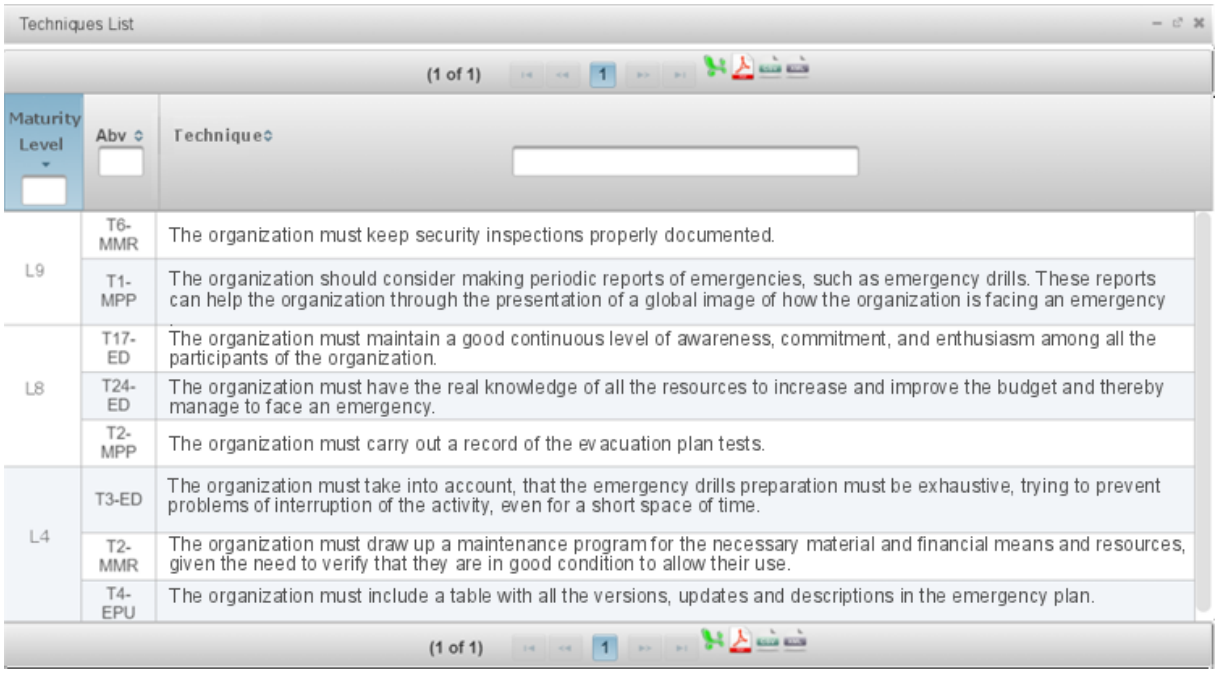


Figure 4. Recommended techniques after the evaluation of the 1F-UPV building (GRP4)

The assessment of the 1F-UPV building also showed that the emergency plan must be accessible to all the workers and not just to a group. For instance, the professors and Ph.D. students had better knowledge of the emergency plan because they are involved in research related to this domain. The Master students were aware of the emergency plan but did not have access to it. The citizens obtained better results than the Ph.D. students because the group of high school students selected had received training through annual simulations carried out at their school.

On the other hand, the emergency drills had not been carried out in the 1F building since 2011, after which the results were analyzed and conclusions were drawn, but no other action was taken. Most of the workers did not have a clear idea of the activities related to emergency drills. Further, after the 1F-UPV building assessment we considered it essential to obtain consistent results in the weights assigned to the *QuEP* questions on the expert evaluation (Núñez et al. 2016b) to give a degree of relevance to the different *QuEP* questions.

Consequently, adequate emergency plan management can increase the quality of all the activities involved, and organizations must focus on improving all the stages involved in the process.

CONCLUSIONS

The official certification of organizations about the emergency plan management is a work in progress. It can be viable as long as experts validated *QuEP* and assessed in real cases. For this instance, we have introduced the first proposal towards the certified through *QuEP*, and we have presented a study case in the 1F-UPV building. Next step is related to test the assessment by *QuEP* in more organizations and elaborate the final reports to each organization. As future work, we plan to contact public administration to propose the certification of organizations in assessing the emergency plan management.

ACKNOWLEDGMENT

We thank Raquel Garrido from the Planning Unit and Vicente Blasco from Departamento de Sistemas Informáticos y Computación of Universitat Politècnica de València (Spain), for their collaboration in the assessment of the 1F-UPV building with *QuEP-tool*. The work of M. C. Penadés is partially funded by MINECO under grant CALPE (TIN2015-68608-R) and the work of A.G. Núñez is partially supported by the Ecuadorian SENESCYT and IECE.

REFERENCES

Baldrige (2014). *Criteria for Performance Excellence | NIST*. URL: https://www.nist.gov/baldrige/2013-2014-criteria-performance-excellence (visited on 10/01/2014).

Berke, P. and Godschalk, D. (2009). "Searching for the good plan: A meta-analysis of plan quality studies". In: *CPL bibliography* 23.3, pp. 227–240.

Camisón, C., Cruz, S., and González, T. (2007). *Quality management: concepts, approaches, models and systems*.

Camisón, C. (1998). "Total quality management and cultural change: a model of organisational development". In: *International Journal of Technology Management* 16.4-6, pp. 479–493.

CPG101 (2010). *Developing and Maintaining Emergency Operations Plans, Version 2.0*. URL: https://www.fema.gov/es/media-library/assets/documents/25975 (visited on 11/01/2014).

Dean, J. W. and Bowen, D. E. (1994). "Management theory and total quality: improving research and practice through theory development". In: *Academy of management review* 19.3, pp. 392–418.

EFQM (2014). *The EFQM Excellence Model*. URL: http://www.efqm.org/efqm-model/model-criteria (visited on 11/01/2014).

UK-gov (2013). *Emergencies: preparation, response and recovery*. URL: https://www.gov.uk (visited on 02/20/2013).

ISO (2011). *ISO 22320, Societal security - Emergency management - Requierements for incident response*. https://www.sis.se/api/document/preview/913934/.

ISO (2016). *Selection and use of the ISO 9000 family of standards*. https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100208.pdf.

JUSE (2014). *Union of Japanese Scientists and Engineers, N. The Deming Prize*. URL: http://www.juse.or.jp/e/deming/ (visited on 11/01/2014).

NBA (2007). *Norma Básica de Autoprotección*. URL: https://www.boe.es/boe/%20dias/2007/03/24/pdfs/A12841-12850.pdf (visited on 09/01/2014).

Núñez, A., Penadés, M., and Canós, J. (2016a). "Herramienta de Soporte a la Evaluación y Mejora de la Gestión de Planes de Emergencia". In: *Jornadas de Ingeniería del Software y Bases de Datos (JISBD)*.

Núñez, A., Penadés, M., and Canós, J. (May 2016b). "QuEP: Building a Continuous Improvement of Emergency Plans Management". In: *13th International Conference on Information Systems for Crisis Response and Management (ISCRAM), Rio de Janeiro, Brazil*.

Núñez, A., Penadés, M., Canós, J., and Borges, M. (May 2015). "Towards a Total Quality Framework for the Evaluation and Improvement of Emergency Plans Management". In: *12th International Information Systems for Crisis Response and Management (ISCRAM), Kristiansand, Norway*.

Singhal, D. and Singhal, K. (2008). *Implementing ISO 9001: 2000 quality management system: a reference guide*. PHI Learning Private.

Towards a Capability Model for Emergency Training Improvement

Patricia Quiroz-Palma
ISSI-DSIC
Universitat Politécnica de Valencia, Spain
patquipa@dsic.upv.es
Universidad Laica Eloy Alfaro de Manabí
patricia.quiroz@uleam.edu.ec

Ma Carmen Penadés
ISSI-DSIC
Universitat Politécnica de Valencia, Spain
mpenades@dsic.upv.es

Ana-Gabriela Núñez
ISSI-DSIC
Universitat Politécnica de Valencia, Spain
anunez@dsic.upv.es
Universidad Nacional de Educación, Ecuador
gabriela.nunez@alttics.com

ABSTRACT

Giving adequate attention to training personnel within an organization to perform an activity of any kind determines its success or failure. Training in emergency management is a key point and the participants must have adequate preparation for each activity they carry out. The different activities in each emergency management phase generate the appropriate training according to the role performed by stakeholders. The training is provided through techniques and IT support tools that consolidate the knowledge imparted by the trainer. This paper describes the initial steps in creating a capability model to support the training of stakeholders and ensure the effectiveness of the response teams, as well as the appropriate actions of workers and citizens in an emergency. Knowledge is consolidated through training, evaluation and feedback from practice. The proposed model is being integrated in the QuEP framework to guide organizations in assessing and improving the management of their emergency plans.

Keywords

Capability Model, Training, Emergency Management, Stakeholders, QuEP.

INTRODUCTION

Emergency training methodologies evolve somewhat later than significant changes in educational methodologies. The training is initially focused on developing the response team's skills. At present, training for emergency management is aimed at developing capacities to respond to emergencies adequately or prevent disasters; it is essential to understand the causes of disasters, risk analysis, and response procedures. The causes of disasters must be analyzed to find the different factors that determine threats and vulnerability conditions (Ferradas et al., 2006).

Appropriate training of participants is of vital importance in all emergency management phases. Although there are general techniques and dynamics for training and improvement of skills (Suixiong P., 2009), we think that customized training in the field of emergency management is essential for organizations. Emergency management should be customized for each of the participants involved in each stage, so that investment in training for emergency management benefits both the person who receives it and the organization that trains them, which will be better prepared to deal with an emergency (or incident). Likewise, the support of Information Technologies (IT) tools in training is important for the continuous improvement of disaster prevention, emergencies, and reconstruction. The main problem is how to improve the training of the people involved in emergency management. Currently, the training is mostly theoretical or based on the experience of the stakeholders, and an evaluation with the corresponding feedback is not carried out after a training. In addition, the use of IT tools to

support training, reduce the high costs of drills and make it possible to apply the evaluation/feedback techniques to improve the training.

This paper proposes a capability model for organizations to define the customized training of all the stakeholders in each stage. This capability model establishes the guidelines to be followed in order to plan, train, validate, evaluate and obtain feedback from the training in an iterative manner, thus achieving the continuous improvement of the stakeholders teaching-learning process in emergency management. This process will be support by IT-tools.

The paper is organized as follows: Section 2 reviews the main concepts related to emergency management, training techniques and the dimensions of training involved in emergency management. Section 3 describes our proposed emergency management capability model, and Section 4 concludes the paper and outlines further research.

TRAINING FOR EMERGENCY MANAGEMENT

The knowledge acquired in training helps people not only to improve their knowledge but also to face emergencies or situations that arise unexpectedly. In fact, to avoid obsolescence of knowledge, periodic training should be carried out as recommended in the training plan. According to Strube (Strube et al., 2011), a training plan is based on activities that can help in collecting information about prospective new systems and the support of resource investments. The training content must contain theoretical information, experiences, and practices (Xing et al.,2010). Other authors, such as Das (Das, 2018), indicate the learning objectives, specify the learning outcomes and the skill and knowledge to be imparted to the learner. Ferradas (Ferradas et al.,2006) indicates the need to identify the study domain from which the contents of the training plan must be defined. From our perspective, good training not only involves a set of activities to be carried out periodically but also includes learning objectives, so that we therefore introduce the concept of the capability plan, which includes both aspects.

Techniques and tools that support the capability process can be applied to implement a capability plan. For instance, Fernández (Fernandez, 2005) indicates that it is necessary to consider the objectives pursued, the participant or group, its maturity, its training, physical environment, psychological environment, and the trainer capacity. Different authors have proposed different training techniques. For example, Ferradas (Ferradas et al., 2006) defined techniques such as interviews, participant observation, life stories, surveys, discussion groups, participatory diagnosis and identification of roles. Suixiong (Suixiong P., 2009) identifies other techniques such as lectures on theories, demonstration and training, individual and group practices. In this work we use the training techniques defined by expert trainers in (Adibi, 2000), who identifies six techniques, including *on-the-job training, conferences, role-playing, audiovisual, programmed learning,* and *simulations.*

The on-the-job training technique consists of assigning new employees to the experienced workers or supervisors who are in charge of actual training. There are several types of this training, the best known being: direct instruction and rotation of the position. The *conference* technique is practical and easy to implement and is a quick and easy way to provide knowledge to large groups. It can be accompanied by printed materials to facilitate learning. The *Role-playing* technique is used to teach sales techniques, interview techniques, to address groups, resolve conflicts and achieve negotiations or hold positions of greater responsibility and consists of having the professionals carry out roles according to the position or tasks they perform. *Audiovisual techniques* are related to the presentation of information to employees through audiovisual techniques such as films, closed-circuit television, audio or videotapes. The *programmed learning* technique consists of presenting a set of questions or facts for the student to answer, then it reviews and compares the answers and repeating the questions with wrong answers until all have been answered correctly. This technique is effective because it gives the employee immediate feedback on the accuracy of his answers and on the learning he is achieving. *Simulation* is a technique in which employees learn in real or simulated equipment the execution of their tasks, for example, simulated handling of machines, vehicles or airplanes. This training corrects errors without actually placing the students in dangerous situations and is almost a necessity in positions where it is too expensive or dangerous to train employees directly.

As technology influences the effectiveness of the training contents and training programmes, the organization should plan and arrange such training contents for the participants to motivate and benefit them. For example, e-training provides many opportunities for business organizations and employee as learners (Singh et al.,2015). The various opportunities include effective use of IT, delivery of updated knowledge and technologies anytime, anywhere and to anyone, cost cutting of training and the just-in-time philosophy. Other tools simulate serious games, as explained in two case studies in Heldal (Heldal, 2016). The first case is a simulated evacuation of a ship on fire and the second case the simulator provides response training in a train crash.

In the emergency management field, the purpose of training is to develop local capacities to respond to unexpected events and/or to prevent disasters. For this reason, it is essential to start from an understanding of the causes of

disasters and their consequences, which takes us to risks analysis. Cause analysis is necessary to determine the different factors that constitute threats and vulnerability to the population.

Ferradas identified the training dimensions in areas such as *Education*, *Social*, *Technical*, *Legal* and *Institutional*, and *Economic*. *Education* deals with the risk management theory and planning for development, disasters and livelihoods, rehabilitation and reconstruction in the perspective of development and minimum standards for humanitarian aid. The *Social* dimension refers to the organization and leadership, ethics and values, memory and history of disasters, perceptions of risk, prevention and adaptation strategies, the prevention culture, information needs, communication media, informal communication, information networks and information campaigns. The *Technique* dimension is related to risk assessment, the preparation of risk maps, the use of databases for geo-referencing and geographic information systems, preparedness and emergency response plans, technologies for disaster prevention and emergency response, early warning systems, damage and needs assessment, psycho-social rehabilitation, operational emergency management and the implementation of temporary shelters. The *legal and institutional* dimension refers to the existing legislation applicable to disaster prevention and response, law and regulation of Civil Defense, local laws and state policies in emergencies, priorities, support systems and distribution of aid. Finally, the *Economic* dimension deals with the economic impact of disasters and the profitability of investment in disasters.

Our proposal to improve emergency management training thus begins by defining a customized capability plan, which should contain learning objetives, activities, and contents classified by dimensions, techniques and tools.

CiET: TOWARDS A CAPABILITY MODEL FOR EMERGENCY MANAGEMENT

We has defined the capability model for emergency management, called the CiET model *(Continuous improvement for Emergency Management Training),* Our work is based on this model which allows customizing the training contents of each activity and emergency phase for each of the participants. The importance of optimal training translates into better resilience in emergency management, as well as reducing the number of victims and costs resulting from an unexpected event. The first step in building a capability plan is to identify the general parameters, such as the dimensions and techniques of the training, the phases, and activities of the emergency management and the expected learning objectives.

The second step considers the importance of the preparation of participants in emergency management. We based this on the Ferradas training dimensions and on the Fernandez techniques and expert trainers to define a capability model that emphasizes the customization of training contents for each of the activities of each phase, considering three phases: pre-disaster, response and post-disaster (Aligne, 2009).

We identified the main contents that will be taught in the training process regarding the activities of the emergency management phases, as shown in Figure 1. In the *planning or pre-disaster* phase, participants should be trained to identify the type of emergencies, to identify means of protection, to know building structures, to know the emergency plan, to know the legal and institutional regulations of the organization, to detect crisis, to carry out risk analysis and to identify an alert (crisis alert). In the *response* phase, participants should be trained in vital issues such as knowing the evacuation routes, identifying signs and using fire extinguishers. The response team should also be trained to use communication and rescue equipment and to give first aid and to act efficiently until the return to normality. In the *analysis or post-disaster* phase, participants should be trained to provide psychological support to victims, analyze damage costs, to improve their resilience to disasters and to identify future risks.

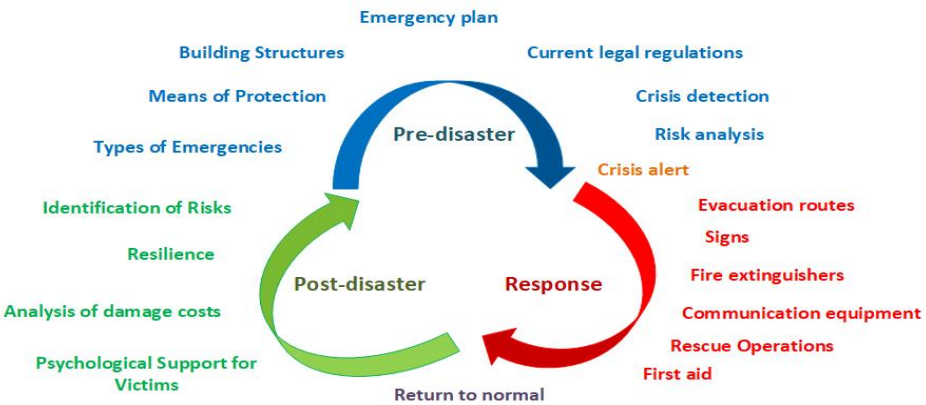


Figure 1. Training in emergency management

The third step was to identify the participants in the capability process, for which we referred to the following classification: organization, planners, workers, responders and citizens (Núñez et al., 2015). In the capability process there are two identified roles, the *trainer* and the *learner*. Organization, planners and responders can play the role of trainer and all the stakeholders fulfill the role of learner. There may also be an external trainer, who is an expert in the subject to be trained and who is not part of the mentioned stakeholders. Table 1 defines the responsibilities of each of the stakeholders and their role in the capability process. The *trainer* is an active participant in this process; this role can be played by some of the stakeholders (organization, planners, response teams). An external expert may also be required, who should be a professional in the subject. The *learners* are all stakeholders trained in the capability process.

Table 1. Stakeholders in the Capability Process (Based on Núñez et al., 2015)

Stakeholders	Responsibilities	Capacitation role
Organization	Access to emergency management legislation. Plan registration. Validation. Education.	Trainer and learner
Planners	Plan design and generation. Notification of planning activities to the organization. Use of planning support tools.	Trainer and learner
Workers	Participation in the planning activities. Education and training.	Learner
Citizen	Access to plans. To follow the instructions of responders.	Learner
Responders	Access to emergency plan. Education and training. Response	Trainer and learner
Expert Trainer	Expert in a specific topic.	Trainer

The fourth step was to relate the stakeholders that participate in the training with the training content and dimension. It is important to be clear about the contents, the dimension to which they belong and the people who should be trained, since adequate training can reduce costs and improve the resilience (Penadés et al., 2017) of people in emergencies (see Figure 2).

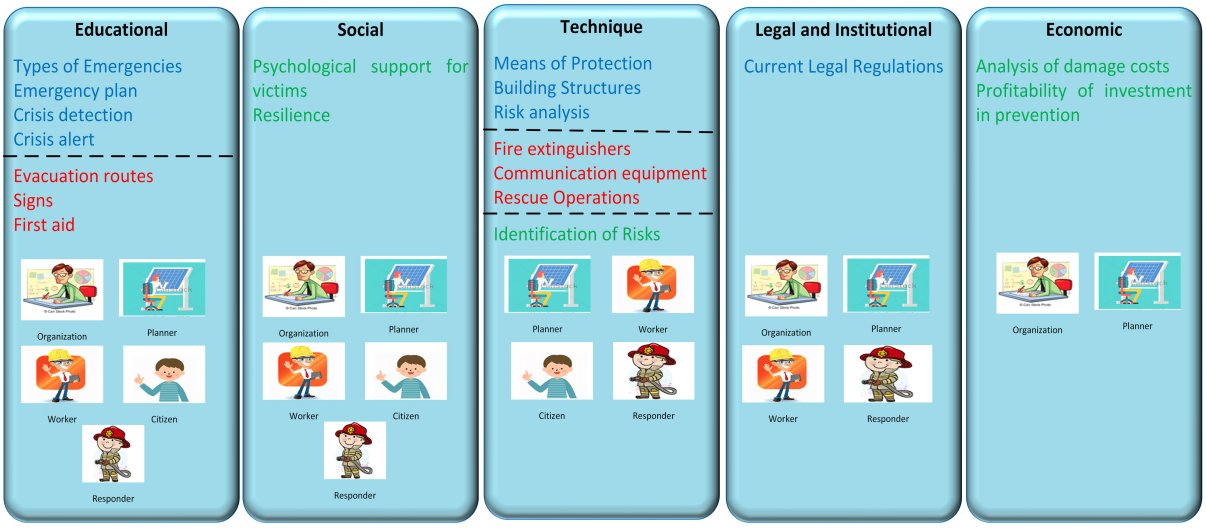


Figure 2. Dimensions, training content and stakeholders

In the Educational dimension all the stakeholders are trained in contents of the pre-disaster phase (emergency types, emergency plan, crisis detection and crisis alert) and the response phase (evacuation routes, signs and first aid). In the Social dimension all the stakeholders are trained in contents of the post-disaster phase (psychological support for victims and resilience). In the Technique dimension all the stakeholders, except the organization, are trained in the contents of the pre-disaster phase (means of protection, building structures, risk analysis, the contents of response phase (fire extinguishers, communication equipment and rescue operations) and the identification of risks in the post-disaster phase. In the Legal and institutional dimension all the stakeholders, except the citizens, are trained in current legal regulations of pre-disaster phase. Finally, in the Economic dimension, the organization and planner must be trained in contents of post-disaster phase (analysis of damage costs, profitability of investment in prevention).

CiET Capability Model

Figure 3 summarizes the proposed CiET capability model as a UML class diagram. A capability plan (represented by the *CAPABITY_PLAN class*) is a set of learning objetives (*LEARNING_OBJETIVE class*) related to the phases of emergency management (*EM_PHASE class*) with their respective activities (*EM_ACTIVITY class*). The training contents (*CONTENT_TRAINING class*) are specified in each of the emergency management activities, according to the dimension (*TRAINING_DIMENSION* class) to which they belong. For each content one or more techniques (*TRAINING_TECHNIQUE class*) and IT tools (*TRAINING_TOOL class*) can be applied. Supporting the learning of the stakeholders (*STAKEHOLDER class*) of the organization (*ORGANIZATION class*) through evaluation (*EVALUATION class*) provides feedback and the continuous training of stakeholders.

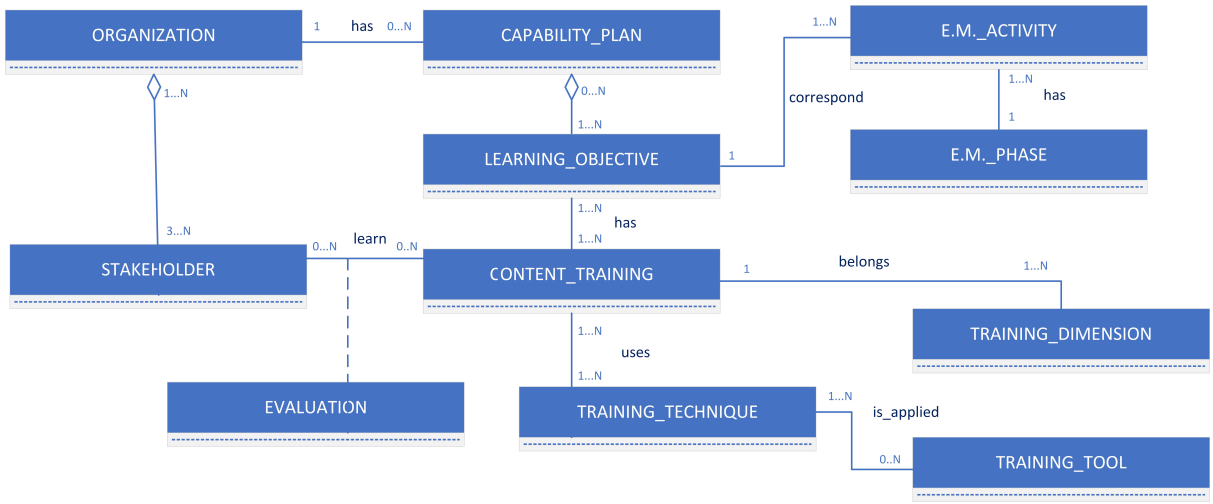


Figure 3. CiET Capability Model

An organization defines the customized capability plans of the stakeholders according to the learning objetives established in the selected emergency management activities. The most relevant aspect the capability plan is to evaluate the training contents and measure the fulfillment of the learning objectives established. If the training contents and learning objectives are not met, the training content should be reinforced, and the evaluation repeated to provide feedback to the learning process and redesign the capabiltiy plan if there are deficiencies in the contents or unreal learning objectives.

Defining CiET capability plans

An organization will define their customized capability plans according to the CiET model. For instance, Figure 4 illustrates different capability plans for the learning objective "Evacuation Routes". CiET Plan 1 is for citizens and CiET Plan 2 for responders. The CiET Plan 1 covers the educational dimension, and the CiET Plan 2 covers the technical dimension and the educational dimension. The trainer in CiET Plan 1 can be an expert trainer or a responder trained, but for CiET Plan 2 must be a expert trainer. Therefore, in CiET Plan 2, the contents are broader and deeper, and the techniques used in each content are more oriented to simulations, audiovisual and practical learning. Finally, it must be evaluated and provide feedback through conferences and IT tools that allow repetitive training and evaluation with comparative results to reinforce the shortcomings found and achieve the learning objectives set.

Evaluation-Oriented Training

One of the main weaknesses of training activities and processes in disaster prevention and response continues to be the evaluation of such activities and the impact of the educational process in general. The evaluation may be related to a specific educational action or to the more comprehensive training process. The evaluation must be done in three stages of the training process. At the beginning, the training process is carried out to identify what knowledge or skills the participant has and adjust the training to the needs of the group (leveling). During the training process it is used to follow up the progress achieved by the participants. In order to assess the levels of knowledge of the beneficiaries and the effectiveness of the training methods, it is necessary to implement ongoing assessment programs during the training and, if possible, to implement any corrective measures. The final evaluation is the most frequently used and can verify whether a sufficient level of knowledge and skills has been reached.

CiET Plan 1		**CiET Plan 2**	
Organization:	Organization X	*Organization:*	Organization X
EM Phase:	Response	*EM Phase:*	Response
EM Activity:	Evacuation	*EM Activity:*	Evacuation
Dimension:	Educational	*Dimension:*	Educational, Technique
Objective Learning:	Evacuation Routes	*Objective Learning:*	Evacuation Routes
Stakeholder:	Citizen, Workers	*Stakeholder:*	Responders
Trainer:	Responder or Expert	*Trainer:*	Expert
Content:	*Techniques:*	*Content:*	*Techniques:*
Building's plan	Conferences,audiovisuals	Building's plan	Conferences,audiovisuals
Routes	Role play, simulations	Protocols	Conferences, practices
Signs	Audiovisuals, practices	Routes	Role play, simulations
Meeting points	Simulations, practices	Signs	Audiovisuals, practices
Restrictions	Conferences,audiovisuals	Meeting points	Simulations, practices
Prohibitions	Conferences,audiovisuals	Tools use	Conferences, role play,
Advices	Audiovisuals	Communication	Audiovisuals, simulations,
		Equipment use	practices
		Restrictions	Conferences,audiovisuals
		Prohibitions	Conferences,audiovisuals
		Advices	Audiovisuals
Tools:	Simulators, serious games, IT Tools customized	*Tools:*	Simulators, serious games, IT Tools customized

Figure 4. CiET Capability Plans

Evaluation-Oriented Training

One of the main weaknesses of training activities and processes in disaster prevention and response continues to be the evaluation of such activities and the impact of the educational process in general. The evaluation may be related to a specific educational action or to the more comprehensive training process. The evaluation must be done in three stages of the training process. At the beginning, the training process is carried out to identify what knowledge or skills the participant has and adjust the training to the needs of the group (leveling). During the training process it is used to follow up the progress achieved by the participants. In order to assess the levels of knowledge of the beneficiaries and the effectiveness of the training methods, it is necessary to implement ongoing assessment programs during the training and, if possible, to implement any corrective measures. The final evaluation is the most frequently used and can verify whether a sufficient level of knowledge and skills has been reached.

Consequently, the key to evaluation-oriented training is feedback. We understand by feedback the answers and comments that are given to stakeholders after performing a training content or evaluation. Feedback has the potential to support academic achievement, promote motivation, self-regulation and self-efficacy, allowing stakeholders to reduce the distance between current performance and desired performance (Seel, 2012).

Feedback is a good way to determine the effectiveness of the training process and the degree of satisfaction of the stakeholders in order to have an accurate idea of what should be improved and where additional training may be necessary. It can be done at the end of each session or at the end of the training. The results obtained from the evaluation and feedback can measure the fulfillment of the learning objectives and achieve the continuous

improvement of the capability process and the CiET capability model.

Finally, the proposed CiET capability model is related to the improvement of the organization's capability. As the CiET model is the basis for defining a process of continuous and customized improvement of the stakeholders' training, it is not simply an isolated proposal to improve training in emergency management, but can be integrated into frameworks for improving emergency management, such as QuEP (Núñez et al., 2015). We are now working on integrating the CiET capability model into the QuEP framework – Level 5 (People) which assesses the participation of the people involved in emergency plans generation and enactment, principally via training and education activities (see Figure 5). This QuEP assessment includes a set of best practiques to improve in each level. The CiET model provides a solution to applied the QuEP recommendations and practices. The main aim of this integration is to obtain an integral and effective solution to improve an organization's emergency management and the capability of the stakeholders by providing customized plans, training techniques and tools, an evaluation process and feedback. The CiET Model can be applied to an organization after its evaluation using the QuEP framework to improve the level 5; the organization needs to implement a capability model for its human resource or for improvement the personal training in emergency management. The validation of the capability model will be done through training experiments to groups of stakeholders, according to QuEP. The experiments will be evaluated to obtain the feedback and apply the continuous improvement of the training and the CiET model.

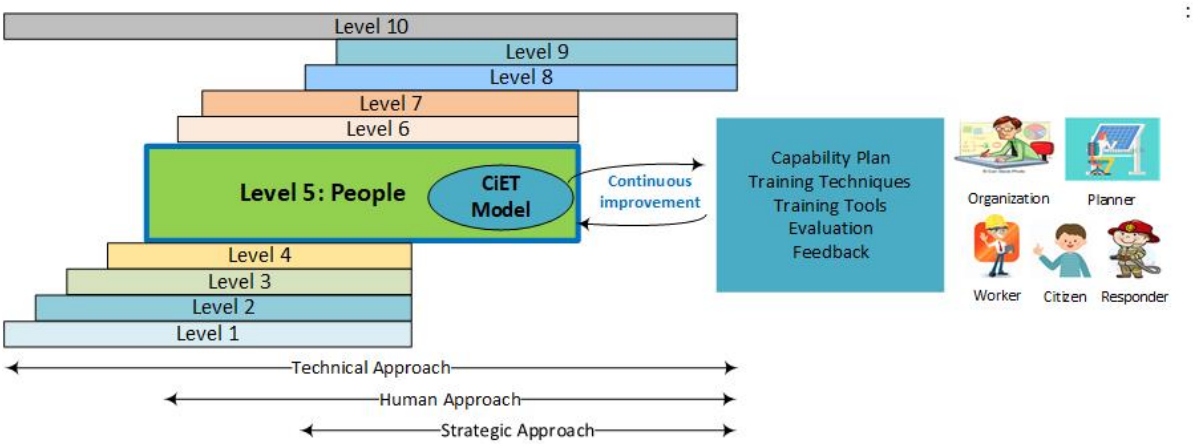


Figure 5. Integrating CiETModel with the QuEP framework (Based on Núñez et al., 2015)

CONCLUSIONS AND FUTURE WORK

The CiET capability model proposed here can identify the elements and stakeholders participating in the improvement of training in emergency management. Training contents are customized and unambiguous for each stakeholder, which means that organizations are better prepared and trained, and the victims, damage and costs are reduced after an emergency. As work in progress, the CiET capability model is being integrated into the QuEP framework to improve emergency management in organizations. In future work, the CiET proposal will be expanded, not only to improve the model and validate it with real case studies, but to develop support and IT tools that support its implementation and implantation.

ACKNOWLEDGMENTS

The work of P. Quiroz-Palma is partially supported by the Ecuadorian University "Eloy Alfaro" of Manabi, the work of M. C. Penadés is partially funded by MINECO under grant CALPE (TIN2015-68608-R), and the work of A.G. Núñez is partially supported by the Ecuadorian SENESCYT and IECE.

REFERENCES

Adibi,M. M., "Bulk Power System Restoration Training Techniques," in *Power System Restoration: Methodologies & Implementation Strategies*, , IEEE, 2000, pp.doi: 10.1109/9780470545607.ch39

Aligne, F. Which Information and Decision Support System for the Crisis Management, *Information Systems and Technology Panel (IST) Symposium*. Bucharest, Romania, May 2009.

Das S., "Cognitive Level Analysis in a Learning Cycle," *2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT)*, Mumbai, 2018, pp. 449-451. doi: 10.1109/ICALT.2018.00111

Fernández, J., Dinámicas de grupos y técnicas participativas, Tarea, Lima, 2005.
Ferradas, P., Vargas, A., Santillán, G. (2006) Ajzen, I. (1988) Metodologías y herramientas para la capacitación en gestión de riesgo deDesastres,Codex, Perú.
Heldal, I., "Simulation and serious games in emergency management: Experiences from two case studies," *2016 22nd International Conference on Virtual System & Multimedia (VSMM)*, Kuala Lumpur, 2016, pp. 1-9.doi: 10.1109/VSMM.2016.7863150
Núñez, A.G., Penadés, M.C., Canós, J.H., Borges, M.R., (2015). Towards a total quality framework for the evaluation and improvement of emergency plans management. *Proceedings of the 12th International Conference on Information Systems for Crisis Response & Management (ISCRAM).*Kristiansand, Norway.
Penadés, M.C.; Núñez, A.G.; Canós, J.H. (2017). From planning to resilience: The role (and value) of the emergency plan. *Technological forecasting and socialchange*. 121, pp. 17 - 30. 2016. ISSN 0040-1625. DOI: http://dx.doi.org/10.1016/j.techfore.2016.12.004
Seel, N. M. (Ed.). (2012). Relevance Feedback Learning BT - Encyclopedia of the Sciences of Learning (p. 2813). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4419-1428-6_5466
Singh, H., Singh, B. P., "E-Training: An assessment tool to measure business effectiveness in a business organization," 2015 2nd International Conference on Computing for Sustainable Global Development (INDIACom), New Delhi, 2015, pp. 1229-1231.
Strube C. M., Loren J. R., "Portfolio influences on Air Force Capabilities-Based assessment and Capabilities-Based Planning activities," *2011 6th International Conference on System of Systems Engineering*, Albuquerque, NM, 2011, pp. 83-88. doi: 10.1109/SYSOSE.2011.5966578
Suixiong P., "Practice and Quest of the Teacher's Training in Educational Technique Ability," *2009 First International Workshop on Education Technology and Computer Science*, Wuhan, Hubei, 2009, pp. 780-784. doi: 10.1109/ETCS.2009.436
Xing Y., Hu S., "Following Construction Study of One Village One College Student Training Plan in Heilongjiang Province," *2010 International Conference on e-Education, e-Business, e-Management and e-Learning*, Sanya, 2010, pp. 436-439. doi: 10.1109/IC4E.2010.46

Towards an Automatic Assistance in Crisis Resolution with Process Mining

Hoang Nam Ho[1]
L3i, La Rochelle Université, France
hoang_nam.ho@univ-lr.fr

Mourad Rabah
L3i, La Rochelle Université, France
mourad.rabah@univ-lr.fr

Ronan Champagnat
L3i, La Rochelle Université, France
ronan.champagnat@univ-lr.fr

Frédéric Bertrand
L3i, La Rochelle Université, France
frederic.bertrand@univ-lr.fr

ABSTRACT

To deal with a crisis situation, experts must undertake a chain of activities, called process, to minimize crisis consequences. To assist the expert in making decision in crisis resolutions, authors propose a method aiming at discovering crisis response processes. This method is based on a two-step strategy: the first step classifies the system's traces, representing stakeholders' past actions, into different sets, where each one represents a set of response processes according to a specific context; the second step uses process mining algorithm to discover the corresponding response plan process model based on the obtained chain of activities for each previously classified context. These response plans will be a referenced aid for experts while making crisis resolution, according to each context. The proposed approach is illustrated on the traces issued from the crisis caused by the 2010 Xynthia storm in France.

Keywords

Crisis management, traces, response plan, clustering, process mining.

CRISIS RESOLUTION: SHOULD IT BE AUTOMATIC NOWADAYS?

Disaster and crisis are real challenges in a practical life. They often are unpredictable (Maryam & Kamran, 2016) and they may cause damage to human lives and have environment and economic consequences. According to (Nikolai et al., 2015), a crisis is defined as "*any event that threatens to, or actually does, inflict damage to property or people*". Crises can be small or large scale, they can happen at any time and their consequences can be very different (Nikolai et al., 2015). Crisis origins are extremely diversified Sauvagnargues, 2018), it can be natural (flooding, storm, *etc.*), environmental (fires, explosions linked to infrastructures, *etc.*), human (terrorism, arson, *etc.*) or technological (virus, computer failure, *etc.*). Few years ago a survey involving 1430 companies worldwide showed that "*despite a significant increase in risks from both external and internal sources, only 47% of companies consider that they are sufficiently prepared to the crisis situations*" (Leblond, 2004). More recently, in (Recovery, 2017) authors claim that "*companies that do not have a crisis management plan are far less able to minimize the crisis's impact*". Over the past few years, we realise that whatever the crises' origin is, the crisis's understanding and the reducing of its damage become more and more important. Moreover, the complexity and the dynamicity of crises make it difficult to understand crisis situation and to elaborate the most appropriate response to it.

To deal with this issue, the term of *crisis management* emerged at the beginning of the 20th century, but it had not been really used till the 1960s. The crisis management encompasses all tasks aimed at resolving crises and reducing their impacts. In the literature, the crisis management is structured in several phases. In (Tufekci & Wallace, 1998), authors proposed an approach with two phases: *before-crisis* and *after-crisis*. The *before-crisis* phase is a prevention and preparation phase that sets up an immediate response to resolve the crisis. The *after-crisis* phase consists in rebuilding and re-establishing the crises' damages. Another approach also involves two phases (Sundar & Sezhiyan, 2007): a *crisis phase,* aiming at mitigating and preparing for crisis occurrence, and

[1] Dr. Ho is now at Kereon Intelligence, France - hoang-nam.ho@kereon-intelligence.com.

a *response phase* that represents all of the actions needed to be carried out as soon as possible to face the crisis. Hereafter, we focus on the response phase in the process of crisis management.

In order to cope with crisis situation, different actors and resources need to collaborate to efficiently respond to the crisis. Actually, actors involved in a crisis resolution perform consecutively their activities following a coordination of the crisis situation called *response plan*. This plan is a kind of workflow that contains activity sequences performed by one or several actors during crisis situations. To model the response plan, many notations have been defined over the past few years. We have chosen BPMN (Business Process Model and Notation) as a notation language for end-users[2] (Object Management Group, 2011). BPMN is a powerful modelling method that can easily model complex real processes such as response plans. It provides a standardized matching between real processes and mathematical formalism that helps authors to be more flexible in manipulating and validating all kinds of business processes. Figure 1 gives an example of a process corresponding to a response plan that describes some prior activities to be carried out at the beginning of a crisis occurrence.

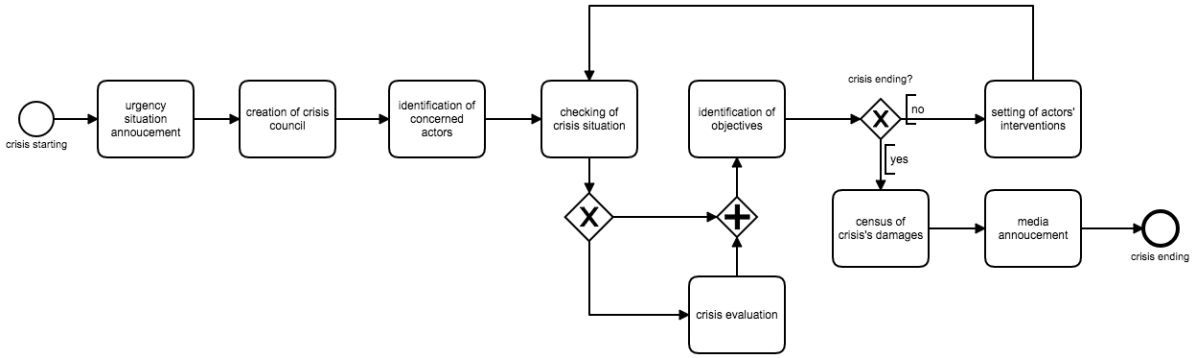


Figure 1. Example of response plan (BPMN) for first time of crisis situation

Crisis's experts are involved as soon as the crisis arise. They supervise the crisis to plan and they decide what should be done to resolve the situation. As depicted in the Figure 2, at each moment, a crisis context is observed. Experts choose a response plan to face the observed context and they must adapt this plan according to the situation changing. The adopted response plan is often based on experts' experience. They are trained to deal with the crisis situation and are able to decide the appropriate activities to carry out. However, there may arise sudden and unpredictable situations that experts have not forecasted. In that case, it takes more time to formulate a suitable plan according to the unexpected circumstances and the lack of immediate knowledge may be another impediment for real-time reactions in experts' decisions. Furthermore, the response plan should be tailored to specific circumstances of various situations that may locally occur during a crisis. As consequence, experts have to develop different response plans to face different crisis contexts.

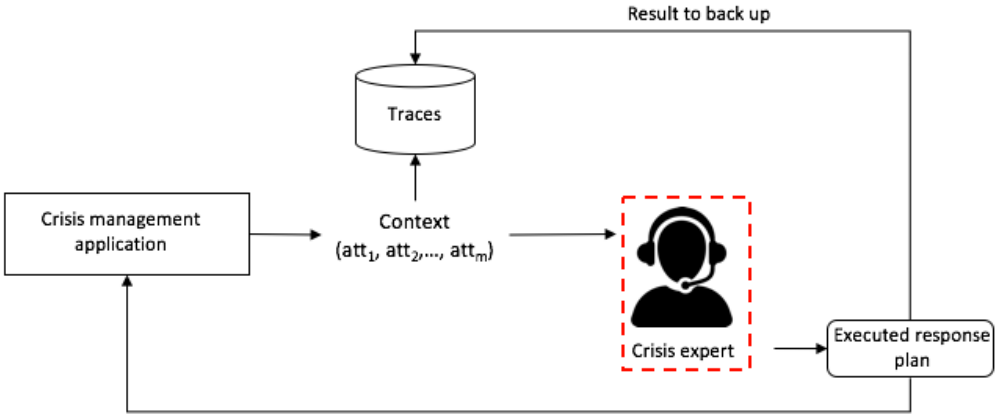


Figure 2. Expert's crisis participation in Crisis Management System

The aim of our work is to assist experts in their decisions. Authors propose an approach that helps experts design a response plan based on collected data from previous crises.

Authors assume that there is a crisis management system at the crisis time. This kind of system includes a database that records all observed events and performed tasks, called *logs*. Observation and evaluation of the

[2] Throughout this research, all of the considered response plans will be denoted in BPMN format.

recorded logs are often based on analysis of large volumes of data representing the contextualized information collected during system's execution, called *traces* (George et al., 2016).

- A *trace* is a sequence of data generated by any action regarding an object or an event occurring during system's execution. It is a set of temporally situated elements.
- Each trace can be associated to a model called *trace model*, that formally represents the corresponding traces. It contains the attributes concerned by the traces, as: *time*, *date*, *user id*, *performed action*...
- The component that allows to collect, handle and analyse traces is called a *Trace-Based System* (Settouti et al., 2009; Lebis et al., 2016).

The traces help us to analyse the previously performed workflow in order to discover the response plan applied at that crisis time. The question is: how to explore the recorded traces in order to get a response plan (workflow type) during the crisis's situation? *Process mining* (van der Aalst, 2016) emerges in the literature as possible response. It represents a set of techniques that could discover business processes from available traces. In our work, a process corresponds to a response plan to a crisis situation.

Authors intend to combine the two aspects introduced above, system's traces and process mining, in order to achieve their main objective: develop a method to assist crises experts in making a response plan at crisis time. The method combines technics from both domains in the crisis management issue. The paper especially focuses on the experimentation of the proposed approach on a real crisis to demonstrate its efficiency and its ability of producing a real-time response plan for crisis situations.

The paper is organized as follows. Next section briefly presents how the crisis resolution is made in the recent years. Then, the case study based on Xynthia windstorm crisis, occurred in February 2010, is presented. It will be used to illustrate the approach and to show its performances. The approach is explained just after, followed by some experimental results and discussion Finally, we conclude the paper and give some guidelines for further research.

HOW WAS CRISIS RESOLUTION MADE IN RECENT YEARS?

A response plan can be seen as a process composed of a set of ordered activities to deal with the crisis situation. The activities and their execution order are described in a predefined scenario or in available official plans. According to a given situation, a concrete response plan must be selected from a set of available alternatives and applied in order to solve the crisis. Over the last years, this topic has risen in importance. In this section, we will examine how responders do in a crisis situation and how to make a response plan to deal with it.

(Le et al., 2017) stated that an activity-oriented process is considered to make a response plan during a crisis. The obtained process model represents activities and exchanged messages between the actors involved in a crisis. Authors have used the α-algorithm (van der Aalst, 2011) to discover the process model from a log file. In (Kushnareva et al., 2015), the BPMN model is implemented to face the flood crisis. This model is predefined based on the collaboration between several actors involved in flood resolution, as the police taskforce, fire brigades, authorities for emergency situations, *etc*. Another application of this approach is used to represent the response plan to face the tsunami in Ho Chi Minh city (Thanh et al., 2013). Authors explain clearly the roles and the tasks of each stakeholder (local administration, local civil defence forces, communication unit, police and health units). The plan assures coordination between these actors. A common drawback in these approaches is that they are based only on textual documents. They specify how to face a crisis and then researchers model the available documents to build a response plan in a process-based notation. It is static and does not take into account past experience: what was done in previous crises and how the predefined procedures were adapted to a given crisis and its contingencies. It is an important source of knowledge that needs to be considered.

Concerning the use of past information to build a response plan in a crisis situation, few works address this issue. In (Negre, 2013), the author exploits the knowledge acquired in past experiences to recommend the best action to deal with the current crisis. A United Nations report points out that former experiences should be taken into account in order to improve the response plan making (United Nations, 2006). The use of past information is also mentioned in (Hanachi et al., 2016). Authors analyse the interactions collected from involved actors during the crisis situation. With this information, authors can discover a meaningful coordination patterns that reflect the organizational structure and the interaction protocols, which are part of the considered response plan. Authors have used process mining techniques (van der Aalst, 2016) with the extension of organizational and interactional dimensions. Another research aimed to discuss the application of process-based in emergent situation (Ariouat et al., 2016). Authors claimed that the collaborative processes in crisis management require a context description for process flexibility. They used the definition of context description in crisis management (Rosemann et al., 2008). Context is defined as the minimum of variables containing all relevant information that

describes it. Context observation allows deciding what should be done to adapt actions to the current situation. Furthermore, a case study of disaster response and emergency management is presented in (Valcik & Tracy, 2017). Authors identify all actors involved in crisis response, but it is a manual work and it is still based on hard-copy documents describing the experiences from other crises experts.

To the best of our knowledge, very few researches deal with the problem of making a response plan in crisis situations. Building automatically such plans is the motivation of our research work. By combining different existing aspects in this domain, we propose a strategy, which is the main purpose of this article, aiming to discover a response plan for each crisis's context based on the recorded traces. We propose to combine two complementary points of view:

- The first one is to use the crisis context to differentiate activities performed by several actors involved in previous crisis situations.
- The second one is related to the use of process mining technics to discover the response plans. Based on the process mining, we can extract the set of response plans corresponding to different past crises' contexts. This set will be used to assist crises' experts during future crises.

The proposed approach is based on traces generated and collected during previous crises, we start by introducing the case study use illustrate our proposed methodology.

CASE STUDY: XYNTHIA WINDSTORM 2010

To illustrate our approach, we consider data sets collected during Xynthia crisis. It was a violent European windstorm that crossed Western Europe from February 27th to March 1st, 2010. In France, civil authorities consider Xynthia as the most violent storm since December 1999, at least 51 persons were killed, and 12 more said to be missing. It reached its highest warning level (red) for five French administrative departments: Charente-Maritime, Vendée, Deux-Sèvres and Vienne.

The Trace-Based System used by the fire-fighters allowed collecting various data. The data set records 274 interventions of fire-fighters for the Charente-Maritime and 277 interventions for the Deux-Sèvres. Each intervention may involve one or several vehicles depending on intervention contexts. In the sequel, we describe how the traces were collected and transformed.

Traces collection

In the considered crisis management application, experts interact with the system by controlling a sequence of activities to respond to the crisis situation. Observation and recording of crises' information has to be done exhaustively. Data retrieved from this step contains all information observed during a crisis. There may be information on the crisis location, information from the crisis operation centre. Besides, experts should choose one response plan according to the current context at each crisis moment. All of these types of data should be captured and analysed to extract the relevant information.

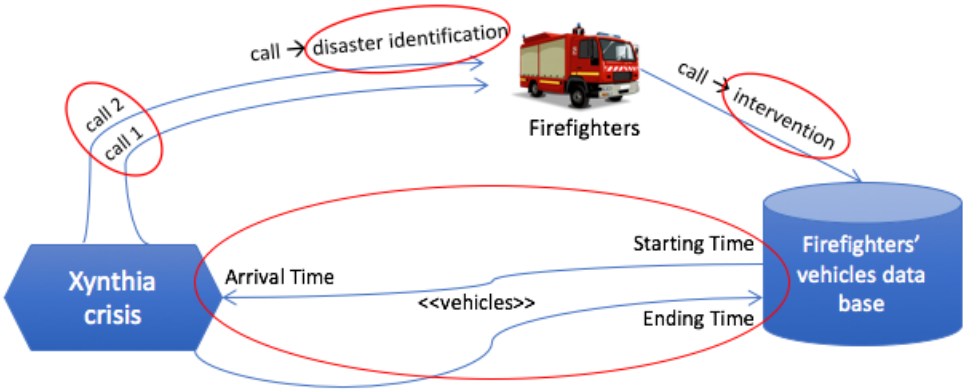


Figure 3. Traces collection in Xynthia crisis

For instance, Figure 3 describes the fire-fighters traces collection process of Xynthia crisis. Citizens and possible victims call the fire-fighter's switchboard to report about the disaster and possibly ask for help. The Fire-fighter's Operation Centre (FOC) receives the calls and based on the caller declarations identify the type of disaster or local crisis situation. According to its classification (*event type*, *severity level*…), FOC creates the corresponding intervention to resolve the reported disaster. Each intervention sends one or several vehicles to

the crisis place to deal with the disaster. The set and the chaining of used vehicles are considered as the response plan for the FOC. Figure 4 gives the model of traces collected during Xynthia crisis. These traces are then used in the *transformation* step.

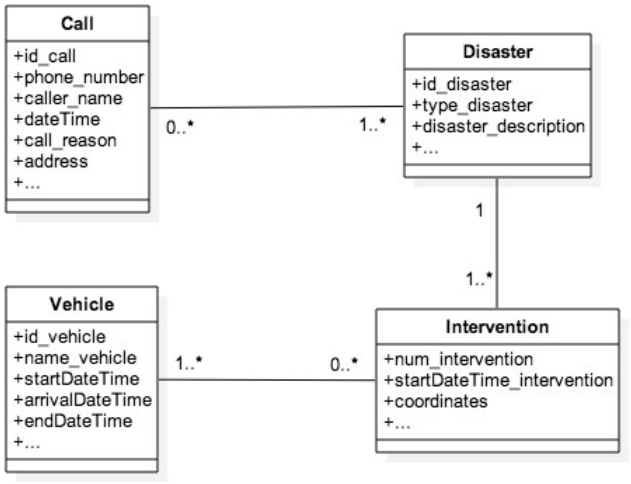


Figure 4. Class diagram of the Xynthia data set

Traces transformation

During this step, collected traces are handled in order to extract the necessary information for the process mining that follows. 3 actions are performed:

- Data filtering: experts should choose one response plan according to the current context at each crisis moment.
- Temporal ordering of filtered data for each intervention: authors need to order temporally all of a_i in A to get a temporal sequence of performed activities. Figure 5 depicts a sample of traces after performing the filtering and the ordering.

context	numInter	name	startDateTime	arrivalDateTime	endDateTime
119	4385	VLCG	2010-02-28T03:34:47	2010-02-28T03:54:47	2010-02-28T06:03:58
119	4430	VTUHR	2010-02-28T04:07:49	2010-02-28T05:08:12	2010-02-28T04:08:24
119	4464	VTU	2010-02-28T04:29:07	2010-02-28T04:52:45	2010-02-28T20:04:32
119	4464	LEPELEC	2010-02-28T04:29:29	2010-02-28T05:05:20	2010-02-28T20:23:19
119	4592	VTU	2010-02-28T07:18:37	2010-02-28T07:27:41	2010-02-28T08:53:28
119	4592	LEPELEC	2010-02-28T07:21:12	2010-02-28T07:29:15	2010-02-28T18:48:43
119	4707	VTU	2010-02-28T10:28:43	2010-02-28T10:44:50	2010-02-28T11:19:20

Figure 5. Sample of primary traces of the firefighters' intervention during Xynthia storm in France

- XES conversion: to use process mining techniques, authors need to transform all of the performed activities into eXtensible Events Stream format[3].

Figure 6 shows a part of the transformed traces that describe the performed activities for the intervention 4257. There are three activities that are executed successively: VTUHR[4], LPS[5] and VSAV[6]. Each one represents the used vehicle at some moment during Xynthia.

RESPONSE PLAN DISCOVERY IN CRISIS SITUATION

The previously obtained transformed traces base is then analysed. In this paper, the traces analysis constitutes the proposed approach and is described in the following. Our strategy to build a crisis response plan from the traces is depicted in Figure 7. We use the transformed traces base T_T obtained in the previous section. The method contains two steps: context classification and mining of the response plan.

[3] IEEE 1849-2016 XES Standard (http://www.xes-standard.org).
[4] VTUHR (Véhicule Tout Usage Hors Route): all-purpose off-road vehicle
[5] LPS (Lot Premiers Secours): first aid bundle
[6] VSAV (Véhicule de Secours et d'Assistance aux Victimes) : victim emergency and assistance vehicle

The first step classifies the transformed traces base T_T into different clusters. Different activities were carried out during the crisis in order to respond to one or several different contexts. Classification's purpose is to gather activities related to each specific context. As a result, we obtain the set of h clusters that will be used in the next step. Each cluster represents the chain of activities performed in the corresponding context.

Figure 6. Example of transformed firefighters' traces during Xynthia

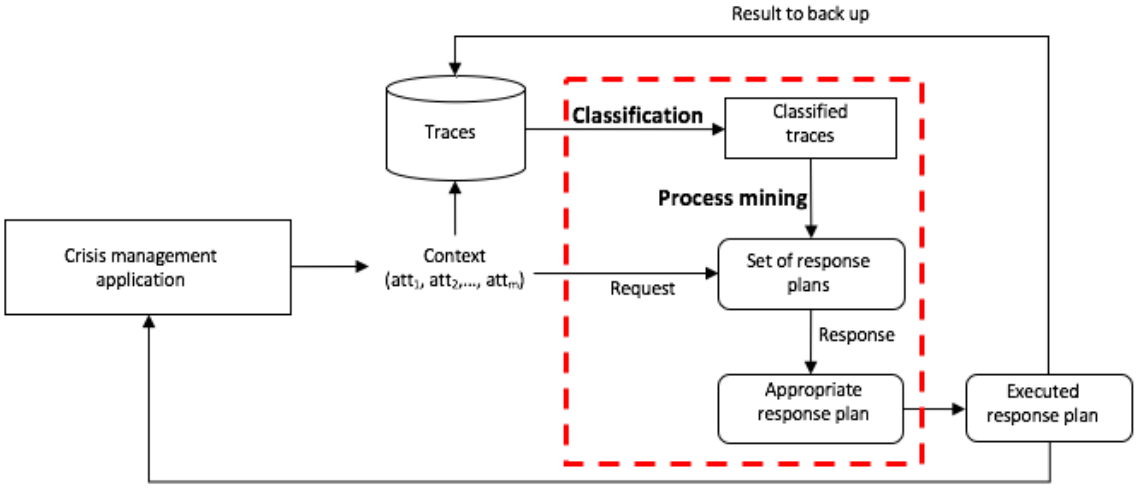


Figure 7. Process of Assisting Automatically a Resolution in Crisis Situation

The second step computes, for each cluster identified above, the response plan corresponding to its context. The discovery of the response plan is based on the chain of activities and is done by applying process mining. Among the available process mining techniques, authors have chosen the Inductive Miner (Leemans et al., 2014). At the end of this step, we discover the entire response plan that has been followed for each context in the recorded past crisis.

The two steps are detailed in the following subsections.

Context classification

The transformed traces base T_T is divided into different clusters according to different contexts distinguished by their attributes. For each context, each concerned actor creates one or several interventions that contain one or several activities to perform. The context classification works as follows. At starting point, it initializes the first record in T_T as the first cluster. Then it computes the centroid context for the first cluster, denoted by $\hat{c}_1$ and obtained by applying the formula (1) on the cluster of N records. It then computes the distance d between the context of the second record in T_T and the centroid $\hat{c}_1$ of the first cluster. The distance $d(context_i, context_k)$ between $context_i=(att^i_1, att^i_2, ..., att^i_m)$ and $context_k=(att^k_1, att^k_2, ..., att^k_m)$ is computed in (2).

$$\hat{c}_h = \left\langle \frac{\sum_{p=1}^{N} att_1^p}{N}, \frac{\sum_{p=1}^{N} att_2^p}{N}, \ldots, \frac{\sum_{p=1}^{N} att_m^p}{N} \right\rangle \quad (1)$$

$$d(context_i, \hat{c}_h) = \sqrt{\sum_{q=1}^{m} (att_q^h - att_q^i)^2} \quad (2)$$

If the distance is less than some predefined threshold s, the second record is added to the first cluster and the value of $\hat{c}_1$ is updated. Otherwise, a new cluster is created with the second record, associated to the centroid context $\hat{c}_2$. The method iterates for all records in T_T and the distance is computed with the centroid context of each already created cluster to determine their respective clusters. At the end, we obtain the set of distinct context clusters.

Traces of the use case are classified according to different contexts by applying Algorithm 1. $C^{Charente\text{-}Maritime}$ and $C^{Deux\text{-}Sèvres}$ are respectively the set of classified contexts of Charente-Maritime and Deux-Sèvres and are the input sets for the next step, mining of the response plan.

Table 1: Context classification result

Department	Number of classified contexts
Charente-Maritime	size($C^{Charente\text{-}Maritime}$) = 25
Deux-Sèvres	size($C^{Deux\text{-}Sèvres}$) = 30

Each element in $C^{Charente\text{-}Maritime}$ and $C^{Deux\text{-}Sèvres}$ is a set of activities performed by fire-fighters in the specific context. For instance, the context type 119 found in the data set concerns 5 fire-fighter's interventions. Figure 8 gives the corresponding traces description.

Figure 8. Example of the five interventions in the context (type 119)

Mining of the response plan

To mine a response plan for each cluster, we apply on the set C above a process mining technique to extract the corresponding process model (representing the response plan) that has been applied in the previous crisis. Among existing process mining techniques, authors have chosen the Inductive Miner algorithm because:

- Crisis traces are always real-life data; they represent exactly what happened in a crisis situation. Inductive Miner algorithm is sound and adaptable for real data.

- Inductive Miner output (process tree) can be easily converted as BPMN.
- Inductive Miner is currently one of the leading discovery approaches thanks to its flexibility, formal guarantees and scalability.

The detailed description of the Inductive Miner's advantages and algorithm is given in (van der Aalst, 2016).

IM is applied to Xynthia crisis's data set to discover a response plan according to every crisis's context. The input of this step is the obtained results of the context classification phase, C, the set of h clusters of traces. For each cluster C_i in C, IM creates a directly-follows graph $G(C_i)$ based on discovered relations between activities in all of cluster records. Then IM selects a type of cut to split $G(C_i)$ into different sub-graphs. An n-ary cut of $G(C_i)$ is a partition of $G(C_i)$ into n pairwise disjoint sets $G_1, G_2, \ldots, G_n$ with $G(C_i) = \cup_{i=1 \text{ to } n} G_i$ and $G_i \cap G_j = \varnothing$ for $i \neq j$. A cut in IM is denoted $(\varepsilon, G_1, G_2, \ldots, G_n)$ with $\varepsilon \in \{\times, \rightarrow, \wedge, \circlearrowleft\}$.

The resulting set P of response plans corresponds to the known contexts. If a new crisis arises, the crisis's context(s) will be observed and compared with recorded contexts to check if there is an adequate response plan previously used in former crises that could be applied in the current crisis. Current and every referred context in P are compared using formula (1). According to this distance, we may suggest response plan from P to resolve the current crisis. It is important to note that the response plan proposed by this approach is still a suggestion for crisis's experts. They could change the response plan or adapt it in any way according to additional real-time data that they may have. Actually, each crisis situation is never really the same as some previous one and there are often unexpected events that arise during the crisis time.

Inductive Miner algorithm is now applied to extract behaviour processes for each context of our use case. The resulting process tree is given Figure 9. In the presented example, intervention 3 involves activity VTU[7] followed by activity LEPELEC[8], in the intervention 4 VTU is followed by LEPELEC and the intervention 5 involves only VTU. The null activity models the fact that sometimes VTU is followed by LEPELEC and sometimes not. This is the reason why we obtain the black rectangle in our process tree. Its formalism is: $\times$ (*VLCG, VTUHR,* $\rightarrow$ (*VTU,* $\times$ (*null, LEPELEC*))).

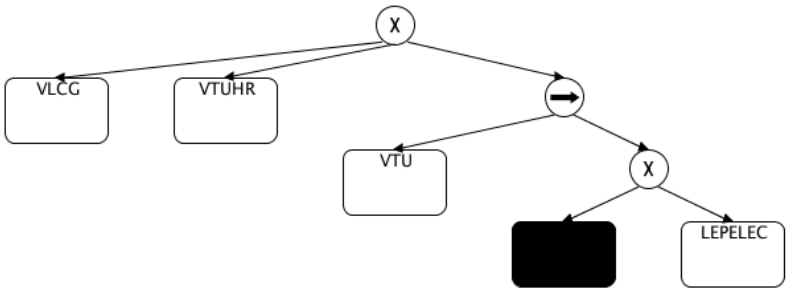


Figure 9. Process tree of the context (type 119)

Finally, the process tree is converted into BPMN. Figure 10 shows the result of this step on the example of Figure 8 and represents the response plan for the context 119. It summarizes what was done by the fire-fighters to face the context type 119 during the Xynthia crisis. The resulting plan becomes a referenced help for the fire-fighters for the next crisis's context of type 119.

The presented example is based on 4 traces, so it produces a relatively simple process tree and response plan. However, with more data more complex process models may be obtained. For instance, the context type 61 that contains 14 traces is modelled by the response plan depicted in Figure 11.

EVALUATION

Authors have assessed the performance of the proposed approach by different tests to evaluate the quality of discovered processes (response plans). Authors focused on the four quality dimensions generally used to evaluate an obtained process model that are:

- *Fitness*: this measure assesses the extent to which the obtained process model could reproduce all the available traces. To measure the fitness, we can replay the recorded traces on the obtained process model to identify mismatches between them. The formula to compute this quality can be found in (van der Aalst, 2016) and (Buijs et al., 2012).

[7] VTU (Véhicule Tout Usage) : all-purpose vehicle
[8] LEPELEC (Lot Épuisement Électrique) : electrical exhaustion bundle

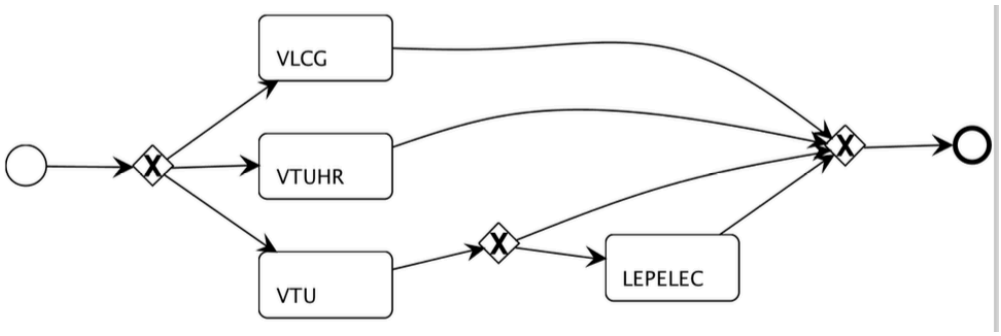


Figure 10. Response plan (BPMN) of context (type 119)

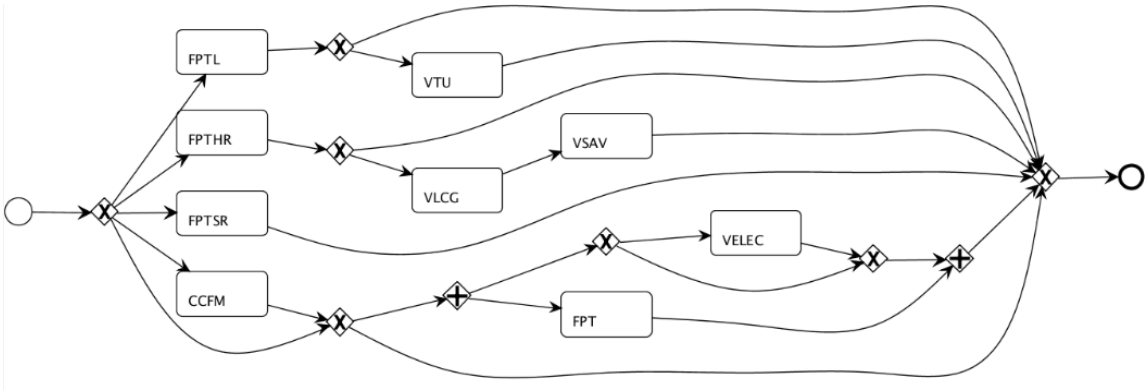


Figure 11. Response plan (BPMN) of context (type 61)

- *Simplicity*: this value represents the structural extent of the process model. This aspect is intuitive and still discussed in the community. The simplicity evaluation depends on the users' point of view. There exist a variety of methods to compute the process model simplicity. We have chosen the structural characteristic to evaluate model's simplicity (Rozinat & van der Aalst, 2008).
- *Precision*: a model is precise if it does not allow too many different traces (Buijs et al., 2012). In other words, precision describes the fraction of the activities allowed by the model but not seen in the traces.
- *Generalization*: this kind of process quality quantifies the extent to which the obtained process model will be able to reproduce the future traces of the process (Buijs et al., 2012). In different terms, the model should generalize and not restrict to the available sequence of activities seen in the already collected traces (van der Aalst, 2016).

The value of these metrics ranges from 0 to 1, close to 1 the quality is more satisfied. It is very difficult to find a balance among the quality dimensions above. For example, precision and generalization cannot be satisfied simultaneously. Four metrics were computed on the obtained process models in order to assess these qualities. However, we especially would like to insist on the fitness quality. Our main research idea is to extract the response plan from the available traces. Authors need a response plan that should represent all of the past activities. The fitness dimension assesses this property.

Figure 12 and Figure 13 are respectively the obtained results on the four quality dimensions above for French departments Charente-Maritime and Deux-Sèvres. Authors focus mainly on the capacity of modelling process based on available traces. If a process obtained by the method is able to replay all the traces, we conclude that the mined process fits well with the past activities (the fitness metric is represented by the blue column in and Figure 13). Authors emphasize that on the two obtained results, the value of fitness is always satisfied (equal to 1). This result illustrates that the process model discovered by the proposed method synthesizes all the processes performed in the past and that the obtained response plan accurately represents what fire-fighters do in previous different crisis's contexts.

The three remained qualities also impact the obtained results in the process mining domain. Based on the number of traces in each cluster, authors could discover a simple or complex process. When the number of traces increases (for instance, context type 47, 22, 118 of the Charente-Maritime and 34, 52, 2 of the Deux-Sèvres), the resulting process model may be very complex (the value of simplicity is always under 0.5). Nevertheless, the more complex the process is, the more its generalization quality deteriorates (the value of generalization is always over 0.5 for contexts mentioned above). Furthermore, the experimentation shows that it is very rare to get

a process model with both high precision and high generalization qualities.

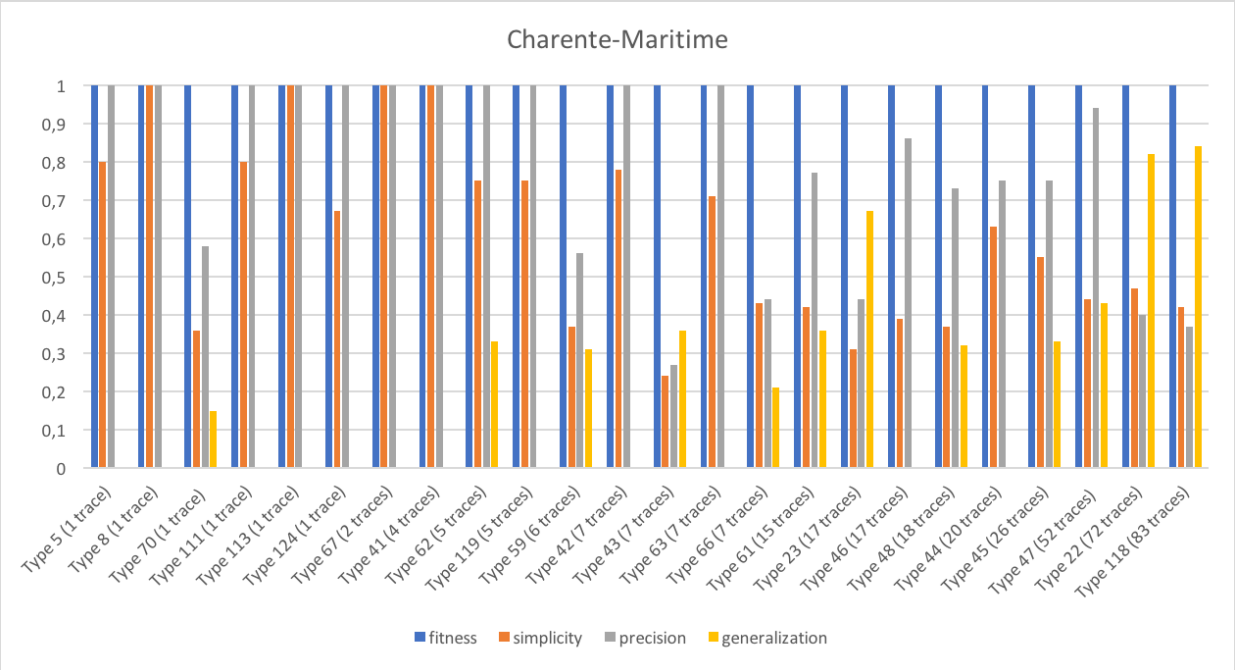


Figure 12. Four quality dimensions on the obtained results (Charente-Maritime department)

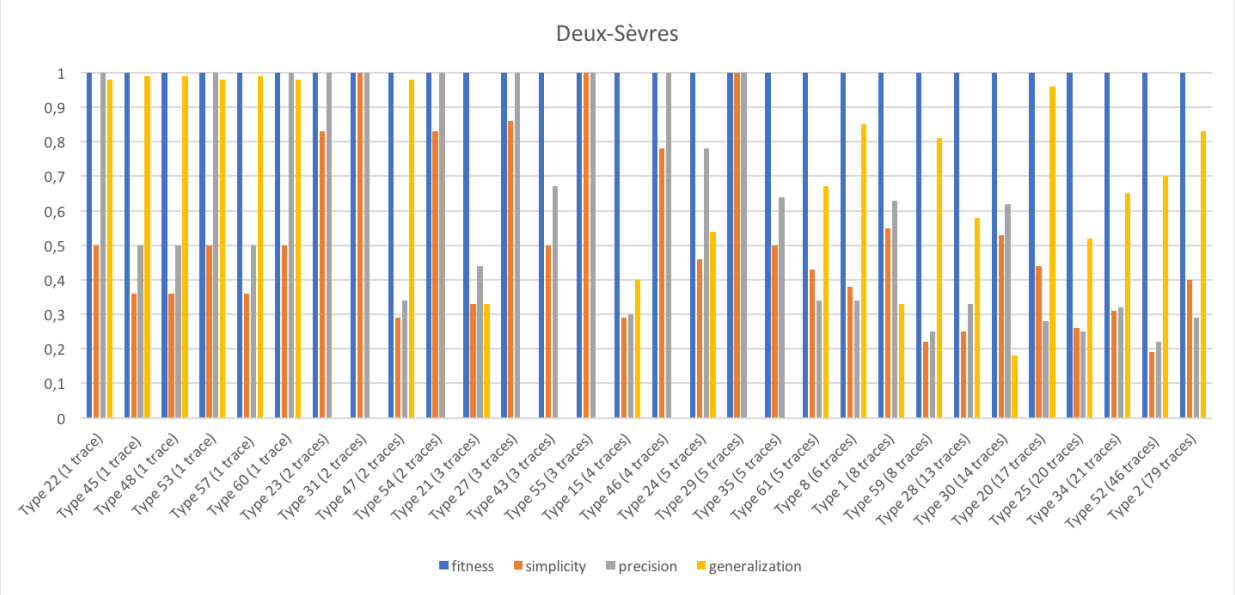


Figure 13. Four quality dimensions on the obtained result (Deux-Sèvres department)

To summarize, the obtained results illustrate that the proposed approach could assist experts during crisis situation. By integrating the context classification in the proposed approach, authors could classify different performed activities for every different context in crisis. By applying Inductive Miner, authors proved its efficiency on modelling a response plan (process) based on activities classified traces.

LIMITATIONS

The approach has some limitations. It is efficient only if enough traces are available. If there is not enough data, we cannot obtain a general process model, the quantity of the available traces directly influences the relevance of the resulting response plan. It is the reason why an expert is always required to assist the response plan validation throughout the time of crisis. In case of non-relevance, expert could change the suggested response plan and adapt it to the current crisis situation.

Another key issue of the proposed method concerns the context classification. This step computes a distance

between a current context vector and each centroid context vector. The value for each attribute in this vector should be numerical in order to apply the Euclidean distance. However, to describe a context of crisis situations, we may have a vector that contains different types of attributes that could be discrete or continue. The used distance formula may not be suitable. In terms of semantics, this type of distance does not take into account the semantic difference between two contexts. The distance computation should be adjusted to overcome this limit. Moreover, each attribute in the context vector has its different relative importance. An attribute may be considered as important in some crisis, but it may be not important in another one. Therefore, multi-criteria weighting (Ho et al., 2014) should be performed to estimate the relative importance between considered attributes in the context vector for each type of crisis in order to overcome this issue.

CONCLUSION

This paper presents a strategy for assisting experts to make a response plan for a crisis situation. The approach is based on the analysis of traces collected during previous execution processes in past crises. A Trace-Based System was adapted to crisis context in order to collect and transform the recorded information. The proposed approach is applied to extract the response plan for each identified crisis context. The approach first classifies the context and the performed activities in past experiences into different sets of activities according to different discovered contexts. Then Inductive Miner, a process mining technique, is used to discover the process model based on the set of previous activities. The resulting process represents the response plan that is suggested as a reference aid for experts to resolve the current crisis.

The proposed approach answers the problem stated at the beginning of this paper: how to automatically discover a response plan in crisis situations? In terms of methodology, we have described in detail how the proposed approach strategy works. Besides, we applied the approach on a case study of fire-fighter's interventions in French departments Charente-Maritime and Deux-Sèvres during Xynthia windstorm crisis in 2010 to assess approach's efficiency.

As perspectives to the presented work, authors intend to overcome the mentioned limitations to get a suitable strategy to different crisis contexts. On one hand, the presented methodology will be included in a crisis management environment under development. This environment aims to provide to experts and to different actors a set of centralized data collection, data visualization and communication tools to deal with crisis situation. On the other hand, we seek to generalize and improve the classification procedure especially by defining a more general and more precise distance computing function including multi-criteria attributes weighting. Furthermore, authors underline the importance of experts' role in crisis situation. Even though, the number of traces will automatically increase over time since the trace-based system of the crisis management environment will accumulate crisis data when new crises arise, authors propose to combine the response plan obtained from the proposed approach with experts' skills and experience. Since the expert remains the qualified decision taker for crisis management.

ACKNOWLEDGMENTS

The research was conducted as part of the GeDyCRisM ERDF-ESF project in collaboration with Systel SA, a french company proviging technology expertise especially for Fire & Rescue Services. Authors particulary wish to thank Fabrice Lainard for his valuable technical feedback.

REFERENCES

Ariouat, H., Andonoff, E., & Hanachi, C. (2016). Do Process-based Systems Support Emergent, Collaborative and Flexible Processes? Comparative Analysis of Current Systems. *Procedia Computer Science*, *96*, 511–520.

Buijs, J. C. A. M., van Dongen, B. F., & van der Aalst, W. M. P. (2012). On the Role of Fitness, Precision, Generalization and Simplicity in Process Discovery. In R. Meersman et al. (Eds.), *On the Move to Meaningful Internet Systems: OTM 2012* (pp. 305–322). Springer Berlin Heidelberg.

George, S., Michel, C., & Ollagnier-Beldame, M. (2016). Favouring reflexivity in technology-enhanced learning systems: Towards smart uses of traces. *Interactive Learning Environments*, *24*(7), 1389–1407.

Hanachi, C., Tahari, M., & Riahi, M. (2016). Coordination Mining in Crisis: A Tool and a Case Study BT - Information Systems for Crisis Response and Management in Mediterranean Countries. In P. Díaz et al. (Eds.), (pp. 107–120). Springer International Publishing.

Ho, H. N., Rabah, M., Nowakowski, S., Estraillier, P. (2014) Trace-Based Weighting Approach for Multiple

Criteria Decision Making. *Journal of Software (JSW)*, *9*(8), 2180-2187

Kushnareva, E., Rychkova, I., & Grand, B. Le. (2015). Modeling business processes for automated crisis management support: Lessons learned. In *2015 IEEE 9th International Conference on Research Challenges in Information Science (RCIS)* (pp. 388–399).

Le, N.-T.-T., Hanachi, C., Stinckwich, S., & Ho, T.-V. (2017). Discovering Crisis Models to Help Assess Coordination Plans. *Vietnam J. of Computer Science*, *4*(2), 97–110.

Le, N. T. T., Hanachi, C., Stinckwich, S., & Ho, T. V. (2015). Combining Process Simulation and Agent Organizational Structure Evaluation in Order to Analyze Disaster Response Plans. In G. Jezic et al. (Eds.), *9th KES International Conference, KES-Agent and Multi-Agent Systems: Technologies and Applications* (pp. 55–68). Sorrento, Italy. Springer International Publishing.

Lebis, A., Lefevre, M., Luengo, V., & Guin, N. (2016). Towards a Capitalization of Processes Analyzing Learning Interaction Traces. In *11th European Conference on Technology Enhanced Learning (EC-TEL 2016)* (Vol. 9891, pp. 397–403). Lyon, France. Springer.

Leblond, T. (2004). *Continuité d'activité : les enjeux réglementaires et financiers* (in french)

Leemans, S. J. J., Fahland, D., & van der Aalst, W. M. P. (2014). Discovering Block-Structured Process Models from Event Logs Containing Infrequent Behaviour. In N. Lohmann et al. (Eds.), *Business Process Management Workshops* (pp. 66–78). Eindhoven, Netherlands. Springer International Publishing.

Maryam, H., & Kamran, M. (2016). A Survey on Smartphones Systems for Emergency Management (SPSEM). *International Journal of Advanced Computer Science and Applications*, *7*(6), 301–311.

Negre, E. (2013). Towards a knowledge (experience)-based recommender system for crisis management. In *2013 Eighth International Conference on P2P, Parallel, Grid, Cloud and Internet Computing* (pp. 713–718). Compiègne, France.

Nikolai, C. M., Johnson, T., Prietula, M., Becerra-Fernandez, I., Madey, G. R. (2015). Design Principles for Crisis Information Management Systems: From Closed Local Systems to the Web and Beyond. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)*, *7*(4), 26–45.

Recovery, D. (2017). What is a crisis management plan and Why you should have it. Retrieved from http://www.proserveit.com/why-you-need-crisis-management-plan/

Rosemann, M., Recker, J., & Flender, C. (2008). Contextualisation of business processes. *International Journal of Business Process Integration and Management*, *3*(1), 47–60.

Rozinat, A., & van der Aalst, W. M. P. (2008). Conformance checking of processes based on monitoring real behavior. *Information Systems*, *33*(1), 64–95.

Settouti, L. S., Prié, Y., Cram, D., Champin, P., Cnrs, U. M. R., & Lyon, U. (2009). A Trace-Based Framework for supporting Digital Object Memories. In *1st International Work- shop on Digital Object Memories (DOMe'09) in the 5th International Conference on Intelligent Environments (IE 09)* (pp. 39–44).

Sauvagnargues, S. (2018). *Decision-Making in Crisis Situations: Research and Innovation for Optimal Training*. Wiley.

Sundar, I., & Sezhiyan, I. S. T. (2007). *Disaster Management*. Sarup & Sons.

Thanh, L. N. T., Hanachi, C., Stinckwich, S., & Vinh, H. T. (2013). Representing, Simulating and Analysing Ho Chi Minh City Tsunami Plan by Means of Process Models. In *ISCRAM (Information Systems for Crisis Response and Management) Vietnam 2013 Conference* (pp. 1–7). Vietnam.

Tufekci, S., & Wallace, W. A. (1998). The Emerging Area Of Emergency Management And Engineering. *IEEE Transactions on Engineering Management*, *45*(2), 103–105.

United Nations. (2006). *Global Survey of Early Warning Systems*. UN report.

Valcik, N., & E. Tracy, P. (2017). *Case Studies in Disaster Response and Emergency Management* (2nd ed.). Routledge/Taylor and Francis.

van der Aalst, W. M. P. (2011). *Process Mining: Discovery, Conformance and Enhancement of Business Processes* (1st ed.). Springer Publishing Company.

van der Aalst, W. M. P. (2016). *Process Mining: Data Science in Action* (2nd ed.). Springer.

From Hindsight to Foresight: using collaborative methodologies to tackle the wicked problems and improve the Emergency System

Marian Zulean
University of Bucharest
mzulean@yahoo.com

Gabriela Prelipcean
University "Stefan cel Mare" of Suceava
gprelipcean@yahoo.com

Florin Druga
University of Bucharest
florin1027@yahoo.com

ABSTRACT

The main goal of this WiPe is to analyze a wicked problem of disaster management, to offer an external evaluation on how the emergency system worked and to plan a foresight exercise able to design a personalized emergency response services to citizens. The first part of the paper is rather a hindsight analysis regarding disaster management of "Colectiv 2015", one of the worst manmade disasters in the recent Romanian history. After four years of investigations and reports and many recovery measures "Colectiv 2015" is still a complex problem that needs external evaluation. The second part of the paper is a two-tier research: an intermediary analysis of the wicked problem, using Barry Turner's framework and a design of a foresight exercise. In the Conclusions of WiPe we propose a design of research meant to: 1) better understand the causes and shortcomings of disaster management and failure of foresight and 2) help the Emergency System in Romania build a disaster resilience mechanism.

Keywords

Disaster, emergency management, wicked problem, Delphi, personalized emergency system.

INTRODUCTION

"Colectiv 2015" was one of the worst manmade disasters in the recent Romanian history, by impact. An accidental fire that lasted a couple of minutes, ignited on October 30, 2015, in a rock club triggered a disaster with 64 people dead and over 150 people injured that eventually led to the massive revolts in the streets of Bucharest, 3 days of national mourning and resignation of the Government. The ongoing criminal investigation opened three files/grounds with 11 people arrested. Further investigation is underway with many conflicting views and interests that lead to the conclusion that "Colectiv" file is a wicked problem that needs external analysis (Arafat, 2016).

On the other hand, the extreme event has been taken into consideration by the Romanian Emergency System in planning but the impact was a major one. An investigation of Zulean and Prelipcean of perception of leaders regarding the risks and preparedness revealed that natural disasters such as earthquakes or large-scale forest fires were considered the most probable and the Emergency System are the most prepared (Zulean and Prelipcean, 2013) while industrial disaster has a marginal attention.

The main goal of this paper is to describe and explain the wicked problem, to offer an external evaluation on

how the emergency system worked (planning, response and recovery) and do a foresight exercise to make the Romanian Emergency resilient in coping with the unexpected events. This will be an academic study of an actual occurrence of the unexpected by examining the unexpected situation, the human roles and actions they took and the results.

The first part of the paper is dedicated to the presentation of the event from the response to recovery. The second part will describe the results of investigations and lessons learned based on Turner's analysis framework. The last part will propose to use a collaborative methodology to analyze the causes of disaster, starting from the results of the Turner's method, and the solutions for coping with unexpected and to improve effectiveness of Emergency System.

"COLECTIV 2015" DISASTER: RESPONSE AND RECOVERY

The unexpected fire occurred on the evening of October 30, 2015 during a concert in the Colectiv Club, where around 350 people were present, according to the participants' estimates, in a place improperly arranged for such activities, as the available data and subsequent investigations showed, fire caused by the fireworks used during the concert, fireworks that led to the ignition of the polyurethane sponge (easily flammable) used for soundproofing on a pillar of the building. Flames expanded very rapidly throughout the club, causing injuries and deaths, through combustion, asphyxia, carbon monoxide intoxication a.s.o., to a significant number of concert participants.

Tragedies such as the Collective Club are not singular, to apply Normal Accidents Theory to understand the extreme events and correct the Strategic Planning process. Several years ago similar type of fire broke out in the Kiss Club in Santa Maria, Brazil on January 27th, 2013, in which 233 people died, and another 630 people were injured (BBC, 28 January 2013). Brazilian police stated that the fire began from a pyrotechnic device that ignited flammable acoustic foam in the ceiling.

Another similar incident took place at a shopping mall in the Siberian city of Kemerovo on 25th March, 2018. The tragedy in 64 dead people, including 41 children (Hayes, 2018). The shopping center was developed in a former candy factory, and the fire safety rules / procedures seem to have been ignored, possibly also as a result of officials' corruption. Another fire occurred more recently, on January 4th, 2019, in an "escape room' game in Koszalin, Poland, killing 5 teenage girls and seriously injuring a man (BBC, 5 January 2019).

Even though considered a "black swan", such events are happening quite often and this led us to deepen the studies and look them from a different perspective, possible as accidents that could be predicted and even prevented by implementing certain rules and procedures.

The Colectiv Club was one of the approximately 50 companies operating in an old hall in the former four-story building of the "Pionierul" factory, starting on May 2013. Changes in the structure of industrial activity have determined that many buildings belonging to former industrial firms change their destination, making possible the emergence of new economic activities in these unused spaces. There is nothing unusual and the economic activity has experienced several episodes over time. Generally, these facilities change their destination, requiring new space improvements and arrangements, and, finally, new operation permit.

The magnitude of the event led the MAI to establish the Red Plan of Intervention, and the Romanian Government decreed three days of national mourning. As a result of the massive protests following the fire, Victor Ponta and his government resigned on November 4, 2015, as well as the Mayor of Sector 4, Cristian Popescu Piedone.

Both from the perspective of the analysis of the events and the existence of theories and practices in the field, it is necessary to analyze the way of intervention, but also the aspects that made possible the functioning of the club as a concert hall and the lighting of fireworks in a closed space, respectively, of what happened in Romanian hospitals and how other countries and international organizations reacted to help our country.

The chronology of events shows the very short fire time, 113 seconds, between 22:30 and 22:32. In another 10 minutes, the first ambulances and firefighters trucks arrived at the scene and the victims were transported to the hospitals, 11 hospitals in the Bucharest-Ilfov region, and in the coming days, on the basis of bilateral agreements, to hospitals abroad. The Red Plan for Intervention at the IGSU level has been activated. Only a few of these 11 hospitals activated the White Plan, a plan that is equivalent to the IGSU Red Plan, but not all hospitals had this White Plan of Intervention (the hospital response plan in the event of a massive influx of patients following a collective accident, etc.). Moreover, there was no centralization and coordination at that time at the Operational Center for Emergency Situations level. At 23:15 came the first news on TV about the incident at the Colectiv Club that initially talked about an explosion with several wounded and dead, and then

about a raging fire. Parents, relatives and friends of some of those who participated in the concert have arrived at the scene asking for information about the victims. The police intervened at 23:30, sealing a perimeter of several streets around the club building, the streets being filled with intervention cars, fire brigades and ambulances. The announcement was initially made by Raed Arafat at 23:55 with a brief press statement: a fire with more injured and 18 dead. At 0:08 Minister of Internal Affairs, Gabriel Oprea, has taken the communication and announced that the number of deaths reached 25. Also, it was made available to people relatives a phone number to receive information and then, at 2:00, the Minister of Internal Affairs reported new data on the fire.

Has the IGSU Red Plan been activated too late, what happened from the operational level - the White Plan of Intervention - in the hospitals, whether or not, in the event of such disasters, would it be the unique coordination at the level of the National Center for Integrated Management, the fire from the Colectiv Club required the activation of the EU Civil Protection Mechanism?

THE LIMITS OF EMERGENCY MANAGEMENT

The presentation of the collective club accident leads to its categorization into the disaster category as an accident involving multiple victims, a collective accident, far beyond the situation of an emergency, defined as the situation where the resources and capabilities exist for each victim/ patient. Therefore, being the most serious civil emergencies incident in recent history of Romania, it is necessary to identify the causes and factors that facilitated the fire, so that recommendations on the measures to be taken to ensure that such "black swan" incidents (low probability - high impact) are eliminated, if possible.

In order to identify the causes of disasters, but also to highlight the limits of emergency management, the analysis can be started from both the past and the future. It is difficult to accurately quantify what involves an exercise of foresight, but we believe it should be an element in triangulation of the results.

The impact and the complexity of interventions in such situations need new approaches and efficient solutions for decision making process in disasters management. Decision makers in extreme risk environments should respond in a different manner because of a new complex and changing global environment and also decision making in critical or special situations is very complex.

Amir Hossein Gharehgozli et all (2016) recommended a framework to deal with wicked problems. However, that is not applicable to “Colectiv” case due to the lack of historical records of past disasters to compare with. So, we found out that Barry Turner’s framework applied by Panos Constantinides to explain the failure of foresight in crisis management for the case of Mari disaster (Constantinindes, 2013).

Most crises are perceived as unexpected events, but several precursors or warnings are usually identified on hindsight by the media or crises investigators. This paradox is at the heart of Barry Turner's failure of foresight framework, who emphasized the process leading up to a disaster, by proposing the following six stages of crisis development which can unfold over long periods of time: Normal starting point, Incubation period, Precipitating event, Onset, Rescue and salvage and Cultural readjustment (Constantinides, 2013). Next we will employ Turner’s framework to clarify the wicked problem of “Colectiv 2015” disater.

Stage I - Normal starting point (1990-2015)

Romania is a country in transition from a Communist organization to a Capitalist way of life and democracy. As mentioned elsewhere, the transition required institutional transformation, privatization and autonomous institutions, including the Emergency System. A set of norms and regulations that address the emergency preparedness and civil protection where designed before 2007, when Romania joined the EU and the implementations continued afterwards. The Colectiv Club was located in a former factory’s hall, being built of reinforced concrete, without windows and having as single available exit a small door of only 80 centimeters. Changes in the structure of industrial activity have determined that many buildings belonging to former industrial firms change their destination, making possible the emergence of new economic activities in these unused spaces. There is nothing unusual and the economic activity has experienced several episodes over time. Apart from being wrapped inside with a soundproof polyurethane sponge, a highly flammable material, it had on the ceiling dry pinewood grilles, which can also sustain fire.

Stage II - Incubation period (2013-2015)

The Colectiv Club was one of the approximately 50 companies operating in an old hall in the former four-story building of the “Pionierul” factory, starting on May 2013. It seems that the existing fire norms and procedures were almost entirely neglected or mimicked since there were hundreds of persons participating in other past events hosted by the respective club, well above the declared number of 80 seats, and the polyurethane sponge on the ceiling was cleaned, most likely with flammable substances. With only three small fire extinguishers and

no water sprinklers, the club operated based on the declaration of responsibility of its owner, without the neccesary approvals for the security in case of fire. However, officers from Emergency Situation Inspectorate were at least 3 times at the club, without taking any concrete steps to ensure the customers' safety.

Stage III - Precipitating event (September - October 2015)

On Friday night, October 30, 2015, a free concert of Goodbye to Gravity rock band was organized. About 350 people were present at the event, according to some participants' estimates.

Stage IV – Onset (30 October 2015, between 21:00 - 22:30)

At 21:00, the concert started and, at 22:30, a new song begun with pyrotechnic effects. The fireworks were installed in the Colectiv Club by two authorized experts. However, the fireworks appear to have not been put at the proper distance to a pillar packed with polyurethane sponge and it began to burn. The flames quickly spread to the club's ceiling and became violent. A dense smoke filled the club and the incandescent pinewood grilles from the ceiling begun to fall over those left in. There was panic and the crowd began to run towards the single available exit. The victims were burned, suffocated or intoxicated with smoke or the emitted gases.

Stage V - Rescue and salvage (30 October 2015, 22:32 – November 2015)

At 22:32, the first call to 112 was recorded and, at 22:42, the first two ambulances and firefighter's trucks arrived at the Colectiv Club. The fire was extinguished quickly, while the medical staff from the ambulances and a new born hospital, located nearby, gave first aid to the severely affected persons and those in the cardiorespiratory stop, the victims being resuscitated in the street. The magnitude of the event led the Ministry of Interior to declare the Red Plan for Intervention and, in the next few minutes, more than 20 ambulances arrived. At around 01:00, the last wounded persons were transported by ambulances or friends' cars to the designated hospitals.

After the first news about the incident appeared on television, on 23:15, parents, relatives and friends of some of those who participated in the concert have arrived at the scene, asking for information. A phone number was allocated in this respect and the Secretary of State for the Emergency Situations, Dr. Raed Arafat, as well as the Minister of Interior, Gabriel Oprea, made press statements to keep the people informed about measures taken in the aftermath of the incident.

Following the fire in the Colectiv Club, 64 people died and another 186 suffered different injuries, 146 of whom were hospitalized. Several people died at relatively long period of time from the incident itself (in some cases, even after few months) due to the complications that occurred, many of which were caused by the improper conditions in the Romanian hospitals, as some independent sources of information say.

Stage VI - Cultural readjustment (November 2015 - today)

Following the incident, three days of national mourning were declared and, on the background of the massive protests, the Prime Minister Victor Ponta and his Government resigned, together with the Mayor of the 4th District of Bucharest, where the Colective Club was located.

Several investigations have been conducted so far, but none have managed to offer a comprehensive picture and provide an objective understanding of the facts. These include two criminal investigations, an extensive Report of the Romanian Government, as well as a Report of the Department for the Emergency Situations and several media investigations.

The first Public Prosecutor Charge was instrumented by the Prosecutor of the High Court of Cassation and Justice against the owners of CLUB COLECTIV S.R.L. and GOLDEN IDEAS FIREWORKS ARTISTS S.R.L for unintentional killings, body injuries and failure to take legal measures of safety and health at work, 8 people being indicted (Ministerul Public, 2017). Among the indictments there were facts such as allowing a large number of people to enter the club, lack of multiple emergency doors and running an improper pyrotechnic show in a closed space. The file is judged by the Court of the District 4, Bucharest.

The second Public Prosecutor Charge was instrumented by the National Anticorruption Directorate for several offences, allegedly committed by people in charge with taking decisions and issuing authorizations in the City Hall of Sector 4 Bucharest, such as: abuse of office if the civil servant obtained for himself/herself or for someone else an undue benefit, forgery when drawing up documents (DNA, 2015). A third charge is under review for the death in the hospitals after the recovery stage.

The newly appointed Prime-minister Ciolos tasked a control team that eventually elaborated an 84 pages report about the "Colectiv" disaster (administrative capacity of the emergency system, its response and management of victims after the medical intervention). The conclusions of the Report were that the response was not well

coordinated with improvisations due to: lack of exercises on major disasters; legislation loopholes and lack of equipment and material resources (Guvernul Romaniei, 2016). As far as the institutions involved their activity has been assessed as properly for the Prefect and Special Telecommunication Service and modest for Emergency Unit "Dealul Spirii" (responsible for the area), Department of Emergency Situations and hospitals involved in intervention.

The Prime-Minister's Report received immediately a response from the secretary of state for Emergency, Dr. Raed Arafat, who elaborated a counter-report of 143 pages with annexes (MAI, 2016). In his conclusions, Dr. Arafat claimed that the PM Report don't uses enough evidence and it is based on media reports, don't understand the terms and the PM final proposal of a radical re-organization of the emergency system is not grounded on a well-established expertise.

A third Report on lessons learned from "Colectiv" has been presented in March 2016 to the public by the Department of Emergency Situations (MAI, 2016b). The Report is based on personal and institutional reports of the people involved in response to the disaster. It analyzes each operative situation since the first call, problems identified, relevance level, lessons learned and proposals. The conclusion of the Report is that the issues were very specific and didn't identified structural causes. However, it suggested an independent analysis by experts to avoid the subjectivity.

From the several investigations and reports, one can identify many causes and shortcomings of response and recovery. Thus, the club was built of reinforced concrete, without windows, and wrapped inside with a sponge for thundering, a highly flammable material, had a single exit, a small 80-centimeter door. On the ceiling there were dry wood grilles, a flammable material.

The club had three small fire extinguishers, but only one was used to try to extinguish the fire at an early stage, but it was not equipped with sprinklers (fire sprinklers) that automatically trigger fire. The representative of the company that dealt with the club's soundproofing said the club's owners refused to buy fireproof material because it was too expensive. Moreover, a month and a half before the event, the clubs' representatives would have washed the sponge on the ceiling, most likely with flammable substances. Secretary of State Raed Arafat confirmed that the Colectiv Club was functioning without the fire brigade's approval for fire safety and the pyrotechnic show. However, 2 officers from ISU Bucharest, George Petrică Matei and Antonia Rad, were at the Collective club headquarters 3 times, without taking any measures to ensure the safety of the clients.

After the immediate response and institutional analyses a set of measures and activities were proposed and implemented for recovery from disaster and to improve of the Emergency System (extract from Government Reports).

a. at the national level the measures were mainly related to the improvement of the IGSU activity: change and adaptation of the legislative framework in the field of emergency situations for the national improvement of the risk types management and accountability of the institutions with attributions in the field; reconfiguration of the integrated emergency response system to streamline the activity of the emergency structures by unifying under the same command the prevention and intervention levels; improving the existing information flow through the integration of emergency and ambulance structures dispatchers; increasing the level of endowment with special vehicles and specific equipment for emergency and disaster interventions to reduce reaction times/ intervention at events and increase the quality of missions, etc.; the establishment of strict rules on the authorization and verification of biocidal products obliging distributors and manufacturers to re-authorize with efficacy tests carried out in accredited laboratories.

b. regarding authorization procedures, where the IGSU can resort to the measure of closing the non-compliant commercial spaces when it finds that the number of clients exceeded by more than 10%, in case of suppression or reduction of evacuation routes or dismantling of special fire extinguishing, signaling and warning, etc. or the requirements for obtaining a fire safety authorization, which regulates the minimum space required for the various activities. As far as the medical interventions in extremely serious situations by adopting a plan of measures to reduce the intervention time consisting in the possibility of triggering the Red Plan by IGSU dispatchers, when there is information about the high probability that the event is a major one from the victim's point of view or by the alert of the ambulances in block, by introducing a unique code, and not individually.

c. lately, the Chamber of Deputies adopted the draft for the completion of Law no. 307/2006 on fire protection, known as the "Colective Law", which establishes an obligation for those who work with the public and who do not have a fire safety authorization to make it clear at all entries.

Those solutions represent just an optimization of ES based on lessons learned from the disaster and not a systematic and sustainable solution to avoid, anticipate or mitigate the wicked problem.

To sum up, we can identify and cluster the causes of disaster in all phases as related with: corruption, legislation, malfunctioning of urban development and emergency systems. All are ingredients of a wicked problem that needs an objective analysis using scientific methodologies.

The Barry Turner's framework in case of the "Colectiv" Club fire rigorously/ scientifically demonstrates that the problems were very specific and the structural causes were not identified by the past investigations. Thus, in our opinion too, an independent analysis should be carried out to avoid subjectivity in trying to unveil the truth about the proper incident and its aftermath.

CONCLUSIONS AND FURTHER WORK

This WiPe paper described the most important manmade disaster produced as a collateral effect of emerging economy without testing the resilience of Emergency System. Despite the fact that there are three files in the courts and at least 8 people arrested, that government itself and the Department of Emergency realized thorough analyses the understanding of "Colectiv" disaster and its causes is far from being clarified. Some stakeholders such as government understood it as a normal accident (Perrow, 1999) and recommends a radical change of emergency system while the leaders of Emergency System denied the failure of the whole system and understand it from the perspective of High Reliability Organization Theory (Roberts, 2010).

This is a clear fact that we faced a complex or wicked problem, with many stakeholders involved and many views about the disaster. Dr. Raed Arafat himself recommended an external analysis (MAI, 2016b). A wicked problem is one where the planning to address adverse events is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize.

On the other hand, Zulean and Prelipcean presented in a TFSC paper how the Romanian Emergency System succeeded to change dramatically on institutional level and strategic planning level and incorporated a knowledge management system (KMS), with the World Bank help (Zulean, Prelipcean, 2013). The Emergency System local leaders expressed an interest in developing an integrated framework under the National Management Information System for Emergency Situations, capable of supporting emergency decisions and ensuring a better interoperability between emergency agencies (emergency unit, police, health sector, and civil protection) in order to provide better support for decision makers. It is surprising that no report mentioned the role of KMS in planning and response to the Disaster.

So, a two-research needs to be done further. A Delphi methodology for both hindsight and foresight to design a personalized emergency response services to citizens.

The first part will be dedicated to deep understanding of the "Colectiv 2015" disaster. That can be part of a hindsight analysis based on a classical Delphi. Our research will use a similar analysis by Panos Constantinides to explain the failure of foresight in crisis management for the case of Mari disaster (Constantinindes, 2013) but will be based on a Delphi questionnaire.

A second stage of the research will use the same foresight exercise based on a Delphi to find out how to increase the disaster resilience of Emergency System in Romania, drawing the research from the TFSC special section "Moving forward to Disaster Resilience". Eventually we will use the Cross-Impact Analysis (CIA) and the Interpretive Structural Modeling (ISM) to build scenarios as tested by Banuls and Turoff (Banuls and Turoff, 2011) and integrate the results into KMS.

Starting from the experience and database of the previous Delphi (Zulean, Prelipcean, 2013) we will design a three-round classical Delphi online, based on Linstone and Turoff (1975) Handbook and experience we developed in Romania a decade ago based on a consultancy and training of professors Murray Turoff and Roxanne Hiltz.

The sampling strategy is determined by our goals: to tackle the wicked problem regarding the causes and mis-management of "Colectiv 2015" disaster and designing a better procedures and preparedness for Emergency System. The main groups to be consulted are: leaders of local emergency units, national leaders of government, associations of victims of disaster, experts in law and civil emergency.

This type of research is not a case study without a significance. As mentioned earlier in the paper, similar accidents, such as Kiss Club (in Santa Maria, Brazil), Kemerovo (in Russia) or Koszalin (in Poland) happened recently but they were considered "black swans". However, our hindsight and foresight will try to find out patterns, will explain the implications for Emergency Systems and will offer policy recommendations for Information Systems.

REFERENCES

Bañuls, V., Turoff, M. (2011) Scenario construction via Delphi and cross-impact analysis, *Technological Forecasting and Social Change*, Volume 78, Issue 9, November 2011, Pages 1579-1602.

BBC (2013) Brazil nightclub fire in Santa Maria kills 233, 28 January 2013 [online], https://www.bbc.com/news/world-21220308

BBC (2019) Escape room fire kills five teenagers in Poland, 5 January 2019 [online], https://www.bbc.com/news/world-europe-46765692

Constantinides, P. (2013) The failure of foresight in crisis management: A secondary analysis of the Mari disaster, *Technological Forecasting and Social Change*, 80, 9, 1657-1673.

Directia Nationala Anticoruptie, 2015, Press Release, available at: http://www.pna.ro/comunicat.xhtml?id=6872

Gharehgozli, A.H. et all (2016) Evaluating a "wicked problem": A conceptual framework on seaport resiliency in the event of weather disruptions, *Technological Forecasting and Social Change,* 121, 65–75.

Guvernul Romaniei, Corpul de Control, 2016, Raportul de control privind interventia de urgenta la incendiul din clubul Colectiv din Bucuresti in seara zilei de 30 oct.2015, available at: http://gov.ro/fisiere/comunicate_fisiere/raport_c.pdf

Hayes, A. (2018) 'Serious violations' at Russian shopping centre ravaged by fire, SkyNews, 27 March 2018 [online], https://news.sky.com/story/shopping-centre-fire-kills-at-least-37-in-russia-11304361

Hernantes, J., Labaka, L, Turoff, M., Banuls V. and Starr R. H. (2017) Moving forward to Disaster Resilience, *Technological Forecasting and Social Change*, 121, 1-6.

Linstone, H.A. and Turroff, M. (Eds) (1975) The Delphi method: techniques and applications, Addison-Wesley, Reading, Mass, available at: http://is.njit.edu/turoff).

MAI (2016a) Punctul de vedere asupra Raportului Corpului de Control al Primului Ministru privind interventia de urgenta la incendiul din clubul Colectiv, available at: http://www.dsu.mai.gov.ro/wp-content/uploads/2016/03/PUNCT-DE-VEDERE.pdf

MAI, DSU (2016b) Raport privind lectiile invatate in urma accidentului de la Colectiv, available at: http://www.dsu.mai.gov.ro/wp-content/uploads/2016/03/Raportul-privind-lectiile-invatate-in-urma-incendiului-de-la-clubul-Colectiv.pdf

MINISTERUL PUBLIC -PICCJ, COMUNICAT, available at: http://www.mpublic.ro/ro/content/c_31-10-2017-12-10

Perrow, C. (1999) Normal Accidents: Living with high risk technologies, 2nd edition, Princeton University Press.

Roberts, K.H. (1990) Some characteristics of high reliability organizations, *Organizations Science*, 1, 160-177.

Zulean, M. and Prelipcean, G. (2013) Emergency Preparedness in Romania: Dynamics, Shortcomings and Policy Proposals, *Technological Forecasting and Social Change*, 80, 9, 1714–1724.

Information collection using process visualisation in the risk management concept for emergency response

Christoph Amelunxen
Computer Application and Integration in Design and Planning
Paderborn University, Germany
amelunxen@cik.upb.de

Janina Isabella Sander
Computer Application and Integration in Design and Planning
Paderborn University, Germany
jisander@mail.upb.de

ABSTRACT

Security-critical processes of emergency response are part of a complex system of people, organisation and technology. They are often characterised by their own dynamics, interconnectedness and information deficits. In addition, a wide variety of stakeholders, some from different organisations, work together, each specialising in a specific area. In order to capture this (process-) knowledge in risk management, information from the experts is necessary. However, experts are difficult to access, often separated locally, cost-intensive and usually have little time (discussion-) capacity. A pictogram-based process visualisation was developed within the risk management concept. The method could be validated within a European project in an expert workshop. This was done using the example of a CBRN mass casualty incident. By using the methods presented, very good qualitative and quantitative results can be achieved from the perspectives of various organisations and their experts. The limited resource ”expert” is used optimally.

Keywords

Pictogram-based process visualisation, risk management, risk identification, emergency response, CBRN

INTRODUCTION

Risk management is a management area, which is described in different areas. It is often not uniformly defined, contains different procedures and is integrated in different ways. In civil security organisations, organisational risk management (RM) is often inadequately described and given little consideration (Montag *et al.*, 2017, pp. 38–40; Kern & Hartung, 2013, pp. 113–114). A consistent approach to operational risk management, which combines strategic and operational risk management in particular, has so far not been conceptualised enough (Kern & Hartung, 2013, p. 114). In addition, retrospective risk assessments are often not carried out methodically, inadequately or sustainably - this presents a major problem.

The current state of research offers numerous sources on risk management, which, however, mostly describe risk management in an industry-specific and different way. It was not possible to establish a direct link to emergency response that would describe an overall concept. Even quality management (QM) is not yet widespread in civil emergency response or it is controversially discussed. (Becker, 2013, p. 15) Therefore, the question arises whether a holistic concept can be developed which can be applied in emergency response. It can be assumed that a sustainable, effective, applicable, accepted and resource-saving concept can be developed from the combination of different concepts.

Standards are the basis for such an approach. Their contents are analysed and brought together under the objectives of the concept for emergency response. Moreover, appropriate methods are highlighted and validated. In addition to the standards and their data, practical experience is available as a basis for information.

RISK MANAGEMENT CONCEPT

The risk management concept considered here is taken from SANDER (Sander, 2018) and is based on the comparison and combination of various elements of ISO 9000 (DIN Deutsches Institut für Normung e.V., 2015), ISO 31000 (ISO International Organization for Standardization, 2009), ONR 49000[1] (Austrian Standards, 2014) and HERCZEG's (Herczeg, 2014) remarks.

None of the risk management concepts in the standards can be fully understood and implemented in terms of emergency response. The concepts can be linked to each other and partly overlap in content. The most important element of ISO 31000 and ONR 49000 is the risk management process (RM process), which contains the risk assessment. For its implementation, ISO and ONR indicate various methods and their evaluation, whereby only the evaluation and description of the methods is comprehensible in ISO. ONR adds emergency, crisis and continuity management as additional elements to the RM process. It consciously deals with the fact that events are not 100 per cent prevented. HERCZEG defines risk as complementary to safety, which is one of the most important qualities. It considers the occurrence of events and their analysis and states that risks are identified and dealt with when designing process control systems and that the risk analysis is part of the event analysis. ISO 9000 considers risks in the form of risk-based thinking in the planning phase of the plan–do–check–act (PDCA) cycle of the QM system. Therefore, the positive aspects of the different standards of SANDER were combined to the following Risk Management concept (Figure 1). (Sander, 2018, p. 94)

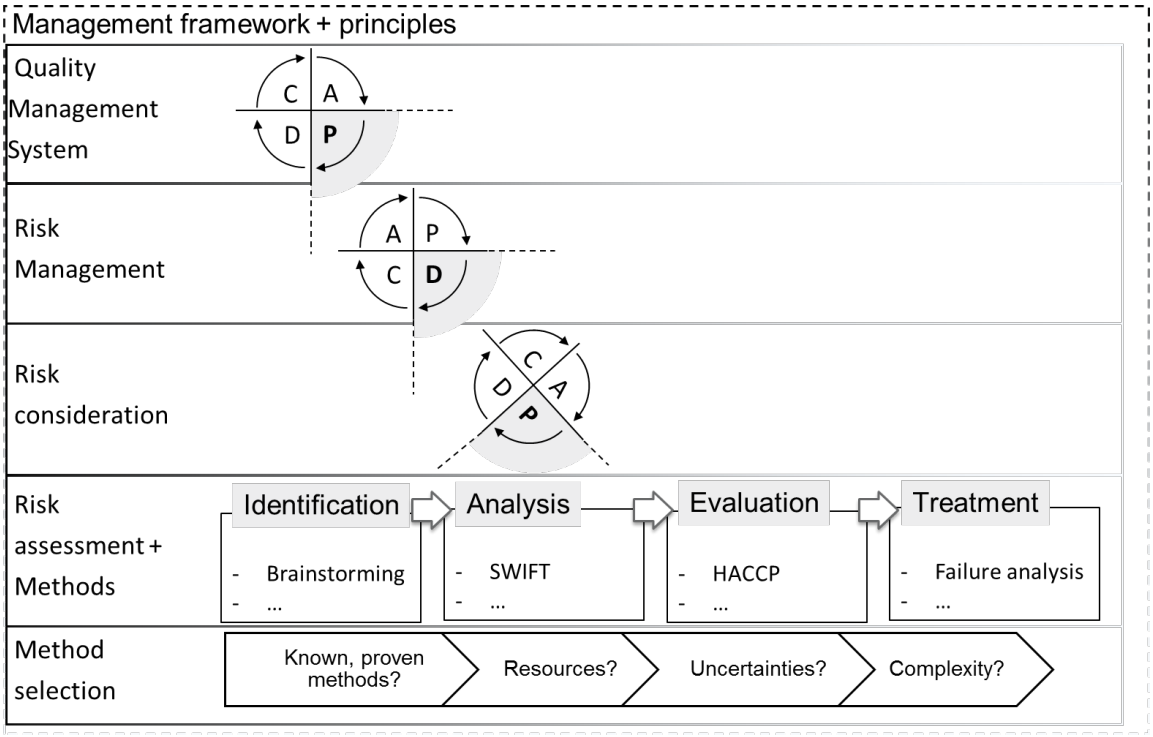


Figure 1. Risk Management concept (according to Sander, 2018, p. 99)

The *management framework* defines the principles and basic framework conditions for a management task in an organisation (e.g. company, institution). It is only intended to provide assistance in integrating the components into the organisation-specific overall management system. The principles are derived from the context, the stakeholders and their expectations of the organisation. The management framework and the principles are set by the top management and are determined by the specific responsible persons. The principles apply at all times and throughout the organisation. (ISO International Organization for Standardization, 2009; Sander, 2018)

Quality management (QM) is a basic management system of the organisation. QM is characterised by its typical PDCA cycle. QM deals with aspects such as the definition of the quality policy, the creation of processes for the implementation of the quality policy and the QM system. In addition, limits and the scope of application are defined as well as regulations for documentation and communication. It is to be implemented at all times and throughout the entire organisation, whereby changes can be incorporated regularly (PDCA cycle). (DIN Deutsches Institut für Normung e.V., 2015; Sander, 2018, p. 96)

[1] Risk Management for Organizations and Systems - Terms and basics - Implementation of ISO 31000

Risk Management (RM) deals with all risk-relevant aspects of the management framework and the QM system. The risk management level in the whole concept corresponds approximately to the risk management framework listed in ISO 31000. The RM is also characterised by its PDCA cycle, which is part of the planning phase of the QM cycle. The RM defines risk policy, agrees risk criteria and establishes a risk culture. This applies at all times and throughout the complete organisation, whereby changes in the RM are also caused by the PDCA cycle. (Sander, 2018, p. 96)

The *risk* consideration (Figure 2) comprises all processes and procedures that are necessary for the proactive and reactive contemplation of risks. On the proactive side, potential risks are minimised in advance and on the reactive side, risks (events) that have occurred are dealt with. Risk consideration is also characterised by a PDCA cycle, which represents the DO phase of risk management. In the planning and implementation phase of the risk consideration, the risk management process is carried out for proactive monitoring. The Check phase consists of the occurrence and noticing of an event. The Act phase is the reactive phase. In this stage, the events are dealt with in concrete terms (according to Herczeg, 2014, pp. 197–198). Risk consideration is the first operational level (from above) that does not take place at management level. It refers to a specific observed process (e.g. production order, production) and can be applied before or during this process. (Sander, 2018, pp. 96–98)

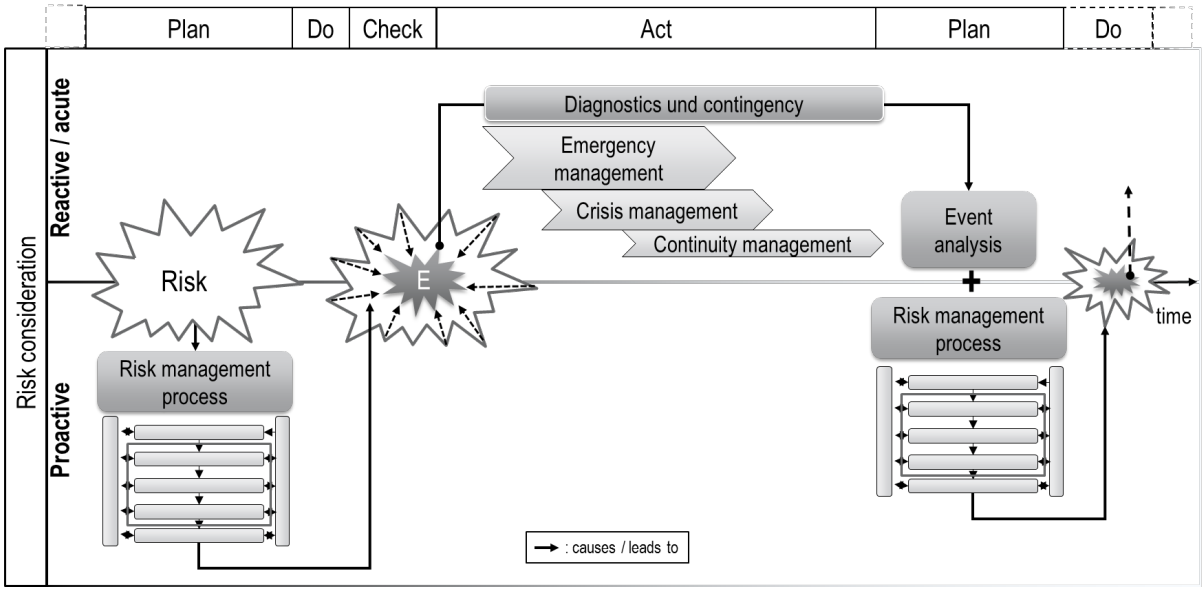


Figure 2. Risk consideration (according to Sander, 2018, p. 98)

Risk assessment is a sub-process of the RM process and an integral part of the planning phase of risk consideration. It represents the lowest level and forms the foundation of the concept presented here. The risks are identified, analysed, evaluated and treated. It is important that *one* risk assessment only applies to the observed process (e.g. production order and production) and the current point in time. Therefore it is part of the PDCA cycle of risk consideration and must be repeated regularly. (Sander, 2018, p. 98) A complex and volatile process should therefore be assessed closely.

When selecting methods, the criteria of known methods, resources, uncertainties and complexity (Figure 1) are applied. The criterion of "known methods" states that methods are to be chosen which are systematically imparted, applied and improved in the organisation of the risk assessor (Herczeg, 2014, p. 155). The nature and quantity of resources required refers to the time and level of expertise, data demands and costs involved. The method(s) to be selected here are those that correspond to the availability of resources in the risk assessment. The nature and degree of uncertainty about the information available and the complexity of the methods chosen must be acceptable to the risk assessor. An evaluation of the methods with regard to the last three criteria mentioned can be found in DIN 31010, so that the risk assessor must compare these with his capacities and guidelines. (DIN Deutsches Institut für Normung e.V., 2010, p. 19, 2010, pp. 21–25)

RISK IDENTIFICATION CONCEPT

Risk identification is part of the risk assessment in which risks are recognised and described. Risk identification lays the foundation for further risk assessment (risk analysis, evaluation and treatment). Since all further steps are based on identification, quality also plays a backward role. It is therefore particularly important to carry out risk identification in a correspondingly good quality.

In this phase, internal and external process risks can be defined and differentiated. The internal risks originate within the process, i.e. within the sphere of influence of those involved in the process and external risks outside the process and the sphere of influence. This means that the identification of risks should not be restricted to those directly involved in the process. The participants (experts) in risk identification should be broadly positioned. For example, in the CBRN process direct process participants (fire brigade) and indirect participants (chemical experts or technology experts) will be involved in risk identification.

When risks occur, one talks about events and their effects[2]. The direct effect of an event can cause consequences, so that events can be defined as the concatenation of causes and effects. (Austrian Standards, 2010, p. 10; Herczeg, 2014, p. 15) A recognised risk can thus be effect and cause too equal.

Risk identification is the process of searching for, recognising and recording risks. More specifically, it is a matter of finding out which circumstances influenced the achievement of the objectives and how these circumstances in turn could be influenced. The risks identified in this way could be events as well as situations and circumstances. In addition to their causes and sources, the consequences of the risks must be determined in their "nature". (Sander, 2018, p. 57; see DIN Deutsches Institut für Normung e.V., 2010, p. 10)

The aim of the risk identification is to develop a list of risks based on events that affect the achievement of objectives in any way. All important and far-reaching causes and consequences should be considered, using tools and techniques adapted to the organisation's objectives, capabilities and risks. (Sander, 2018, p. 57; see ISO International Organization for Standardization, 2009, p. 17)

Risks therefore arise from one or more sources. These constitute uncertain influences from various areas (internal, external) with the participation of a wide range of stakeholders. Risk is the result of a combination of likelihood and impact. At the same time, it represents the link between cause and effect. From this it can be deduced that risks and their identification represent a very complex construct. Depending on the goal, perspective and observer, different results can emerge or risks can be identified. In addition, identification requires a high level of knowledge (expert knowledge) about the object under consideration (e.g.: process) and a lot of development time. This is in direct contrast to reality. There are only a few experienced experts for certain safety-critical processes. They are also difficult to access, often separated by location, cost-intensive and usually have little temporal (conversation) capacity.

Methodological sequence

The methods for risk assessment and risk identification presented in ISO and ONR all have an implicit prerequisite: *a common understanding of the object under consideration* (here, below: process). This is achieved by the following concept. The consideration can refer to different questions or goals, e.g. risks, requirements. The methodological procedure is shown in the following diagram (Figure 3).

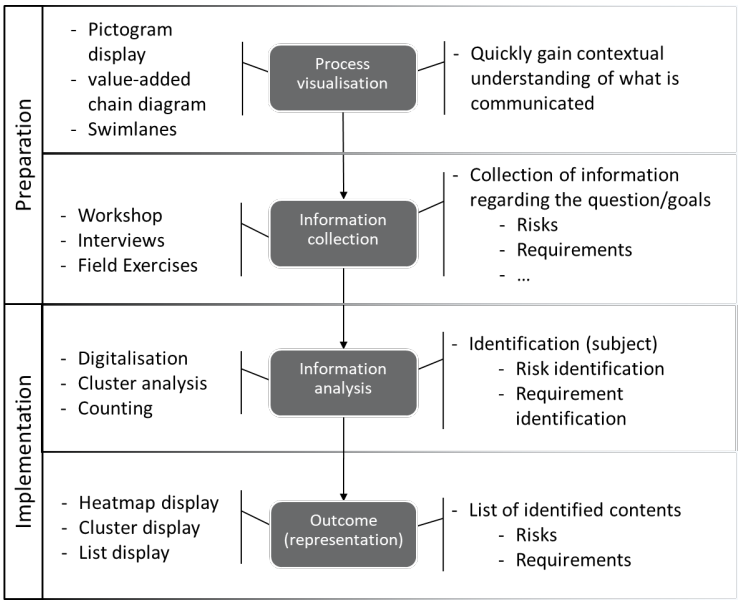


Figure 3. Methodical process of risk identification

[2] An effect is the outcome of an event affecting the targets. Austrian Standards (2010, p. 10)

The first step of the visualisation lays the foundation for a common communication. It is essential to ensure that the same things are spoken of in the following steps. Due to the different experiences of the individual stakeholders, a detailed information collection is connected to the visualisation in order to consider all possible aspects. In the analysis of this information, the actual identification takes place. The identified objects must then be presented in a final step as a result of the process.

Process visualisation

The emergency response situations fulfil the Hofinger characteristics of complexity (according to Hofinger, 2013, pp. 3–8) and can therefore be described as complex situations. Complexity is characterised, among other things, by a high degree of inherent dynamics, a high degree of interconnectedness and a lack of information. It follows from this that the actual problem cannot always be determined. In their search for a scientific basis for such problems, Rittel and Webber have defined the "Wicked Problems" (Rittel & Webber, 1973, pp. 155–169) in the field of planning processes. With the "Wicked Problem" the concrete description of the problem and thus also its solution eludes the observer. This description can therefore also be assumed for emergency response.

If problems and their solutions are not explicit, there are many possible courses of action. These can be implemented in the process visualisation in two ways. On the one hand, there is the possibility to limit or define the actions or the problem by framework conditions and thus to enable a detailed representation. On the other hand, the representation can remain abstract in order to consider as many options for action as possible and thus possible risks. In the case of the holistic view, with many stakeholders, of processes of emergency response, an abstract representation should therefore take place.

The more a process diagram explains, the less it is understood (Herrmann, 2012, p. 170). In order to avoid this, an intentional incompleteness is created in which the critical segments are represented disproportionately present and at the same time other details are omitted. Thus the goal of the representation is emphasised, the complexity of the process is reduced and the comprehensibility is increased. At the same time, the abstract representation creates an open image that leaves room for free thinking, e.g. for risk or requirement identification. The omission of explicit descriptions prevents the discussions from drifting into a kind of "definition discussion" and becoming resource wasters.

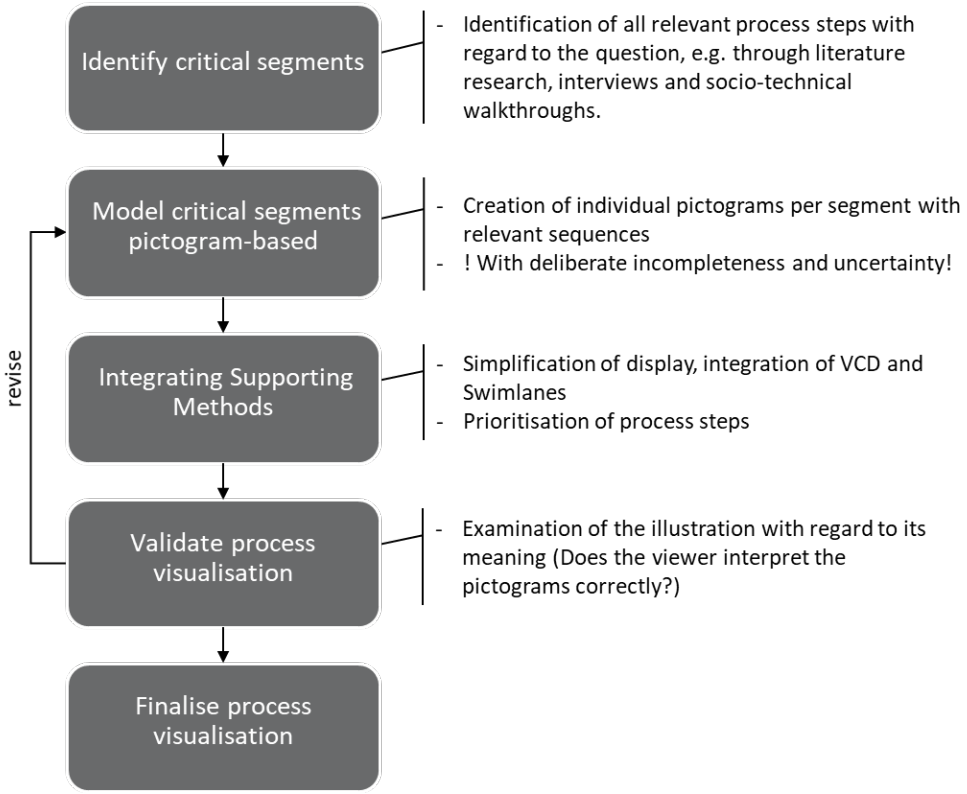


Figure 4: Procedure for process visualisation

This approach to process visualisation (Figure 4) makes it possible to create a simple representation (Figure 6) which simplifies complex topics and presents them in an understandable way so that the information can be used effectively. In addition, it is easy to use, quickly available and can be adapted individually. This makes it possible

to reach a good quantitative and qualitative result with several experts in the information collection in a short time. The focus in process visualisation is on pictogram-based presentation.

Pictograms serve as part of a visual world language of the transmission of information. They have a simple form of design with a character of challenge and visual language and are application-specific. By using pictograms, relationships and dependencies between processes can become more understandable for the end user. Pictograms can be iconic, symbolic, or hybrid. Iconic pictograms depict objects or situations that are very easy to understand. Symbolic pictograms, on the other hand, use characters that must be defined and learned. Hybrid pictograms combine these two types and are supplemented by text elements. (Hasselbring, 1998, pp. 217–218; Böhringer *et al.*, 2011, p. 411)

Thus the pictograms concerning their use in the process representation fulfil the requirement of a fast comprehensibility after HERMANN (Herrmann, 2012, p. 156). The type of presentation has references to the already existing world of experience, its syntax and semantics are simply structured, no high memory performance is required and it provides simple means of expression.

The pictogram-based visualisation serves as a reference process for the various expert groups (Figure 5). It represents the function of information collection and communication by forming the "bridge" between the different expert groups and thus connecting them with each other. The processes are made comparable on an abstract level. Even if the process flows look different in detail for the individual stakeholders, they can still be assigned to a reference process step. On the one hand you can communicate directly without prior definition description, e.g: "In zone 2 we always have the problem of ...", on the other hand individual information (e.g.: risks) can be assigned directly. Stakeholders are divided into four groups. Internal and external describes the affiliation of the respective stakeholders. The affiliation can relate to different areas, such as Project staff, company affiliation, working groups. (Partial) process knowledge and process unfamiliarity describes the level of knowledge of the respective stakeholders about the object (process) under consideration.

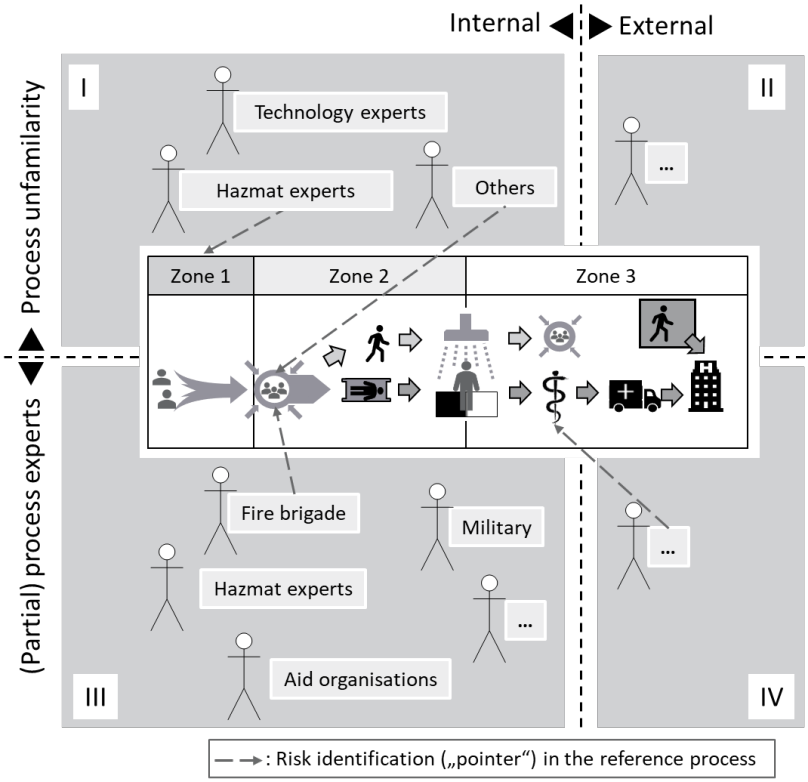


Figure 5: Information collection function of the reference process (example: CBRN process)

The process visualisation can be optimised in addition to the pictogram-based representation by integrating the following methods.

The method of *Swimlanes* is a concept for organising and structuring processes through separate visual categories. This type of spatial planning is used to further simplify the visualisation. The description of the swimlanes is not bound to any conventions.

Value-Added Chain Diagrams (VCD) represent the process compared to the pictograms in a text-based form. With

this form of representation, additional relationships and information can be visualised alternatively. In addition, other process levels can also be displayed. (Amelunxen *et al.*, 2018) This enables process modeling for a detailed analysis of the processes. It should only be used for support and should not undermine the objectives of the abstract representation.

The process representation (Figure 6) shows the different visual methodological contents described above. Here the vertical swimlanes divide the process according to the spatial order. They offer the possibility to discuss the process in an even more abstract way. Independently of this, the horizontal swimlanes allow further options of classification. The pictograms or process steps can also be moved into the respective lanes. A special case of spatial decoupling of process steps is represented by an inserted block within a lane in order to be able to form a basis for discussion here as well. If it is necessary to consider the temporal course of a process or sub-processes, different versions with the respective changes are created. (Amelunxen *et al.*, 2018)

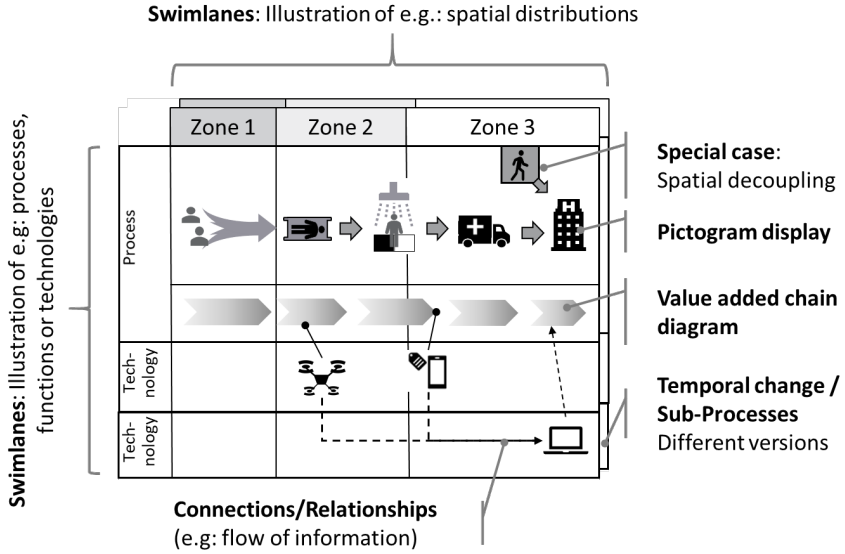


Figure 6. Process visualisation using the example of the CBRN reference process with technical systems (according to Amelunxen *et al.*, 2018)

RISK IDENTIFICATION IN THE EU PROJECT „TOXI-TRIAGE“

Within the European project „TOXI-triage[3]“ an adaptive European triage process for CBRN layers in connection with new technologies is being developed and improved. It is an interdisciplinary European project in which different native languages are spoken. The CBRN process is subject to various national laws and is described, implemented and executed by various stakeholders.

In Germany alone, for example, a total of 64 laws regulate the decontamination of injured persons at federal state level. In principle, four different legislations are involved: the Police Act, the Fire Brigade and Fire Protection Act, the Disaster Control Act and the Rescue Service Act. The 16 federal states each describe this in two to six different laws. (Densow *et al.*, 2005, pp. 28–33)

If one extrapolates this number of laws to the European levels, it quickly becomes clear that it is difficult to establish a common definition. It is therefore important for risk identification to address the question of how the process can be communicated on the one hand and how it can be ensured that all stakeholders have the same understanding of the subject under discussion on the other. To generate this common understanding, the CBRN process is visualised.

The above-mentioned properties of pictorial information transmission are implemented here. In the information collection (risk identification) different groups of persons from the project meet, e.g. from different occupational fields, organisations and countries. In particular, their communication is sometimes fundamentally different with regard to designations and definitions, which leads to problems. In order to counter these problems, the above-

[3] Integrated and adaptive responses to toxic emergencies for rapid triage: engineering the roadmap from casualty to patient to survivor (TOXI-triage); This project has received funding from the European Union's Horizon 2020 (H2020) research and innovation programme under the Grant Agreement no 653409.

mentioned method of process visualisation is used. This keeps the introductory phase of the workshop, in which a common understanding of the object under consideration is generated, extremely short.

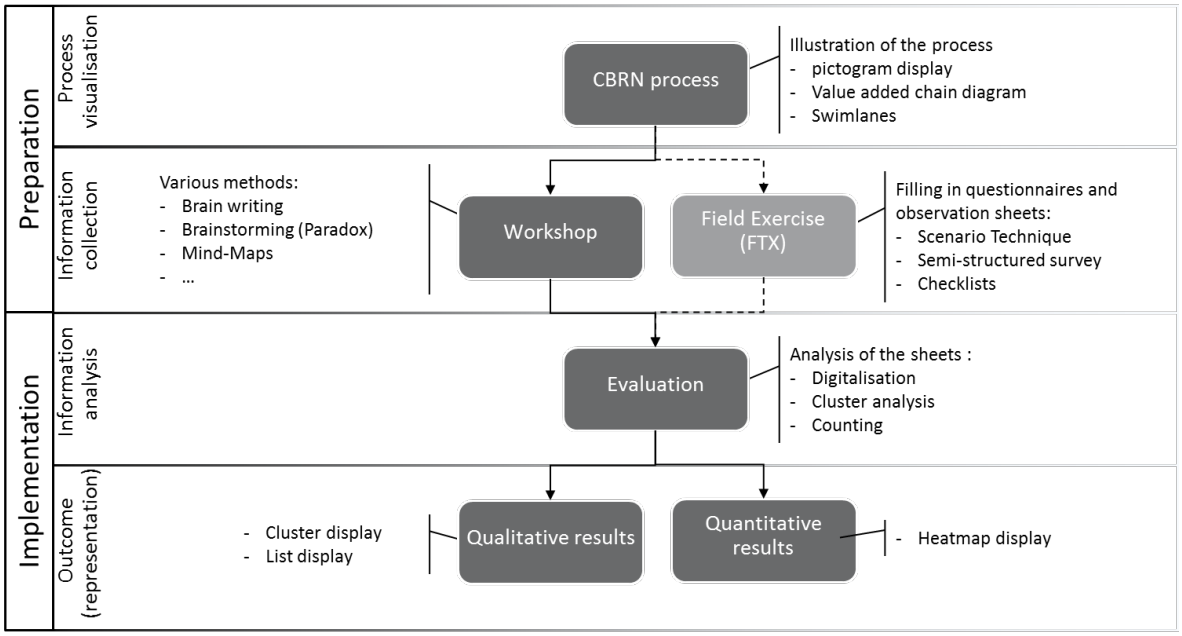


Figure 7. Risk identification procedure

Different methods were selected for the information collection in the framework of the EU project TOXI-Triage. The methods are used in modified variants in order to be able to use the already pre-planned project activities. This minimises the additional effort and counteracts the scarcity of resources (resource: process knowledge). Basis of the risk identification (Figure 7) is first the *process visualisation* for the CBRN process, which should serve as discussion basis and reference model in the inter-European environment.

The process visualisation is inserted as a template in the workshop and as an orientation aid in the questionnaires as well as in the observation sheets of the Field Training Exercises (FTX). The workshop and the exercise take over the information collection step. They work with creativity techniques as well as the scenario technique, the checklists and the semi-structured survey. The information collection as well as the information analysis and the presentation of results for the workshop have already been completed and are presented below.

Workshop

Risk identification through the workshop (method according to (Rupp, 2007; BMI/BVA - Bundesministerium des Innern/Bundesverwaltungsamt, 2018)) is implemented through various creativity techniques (Figure 8) (Nöllke, 2015; Rupp, 2007). The workshop[4] was attended by 59 experts from the fields of fire brigade, medicine and rescue, military, research and others. The participants worked in nine small groups on the tasks set by moderators and guided by them. The moderators with practical experience in emergency response were prepared for the workshop according to the moderation method (BMI/BVA - Bundesministerium des Innern/Bundesverwaltungsamt, 2018).

[4] A Workshop/Master Class on Triage & Toxicity, August 30, 2017, Düsseldorf (Germany)

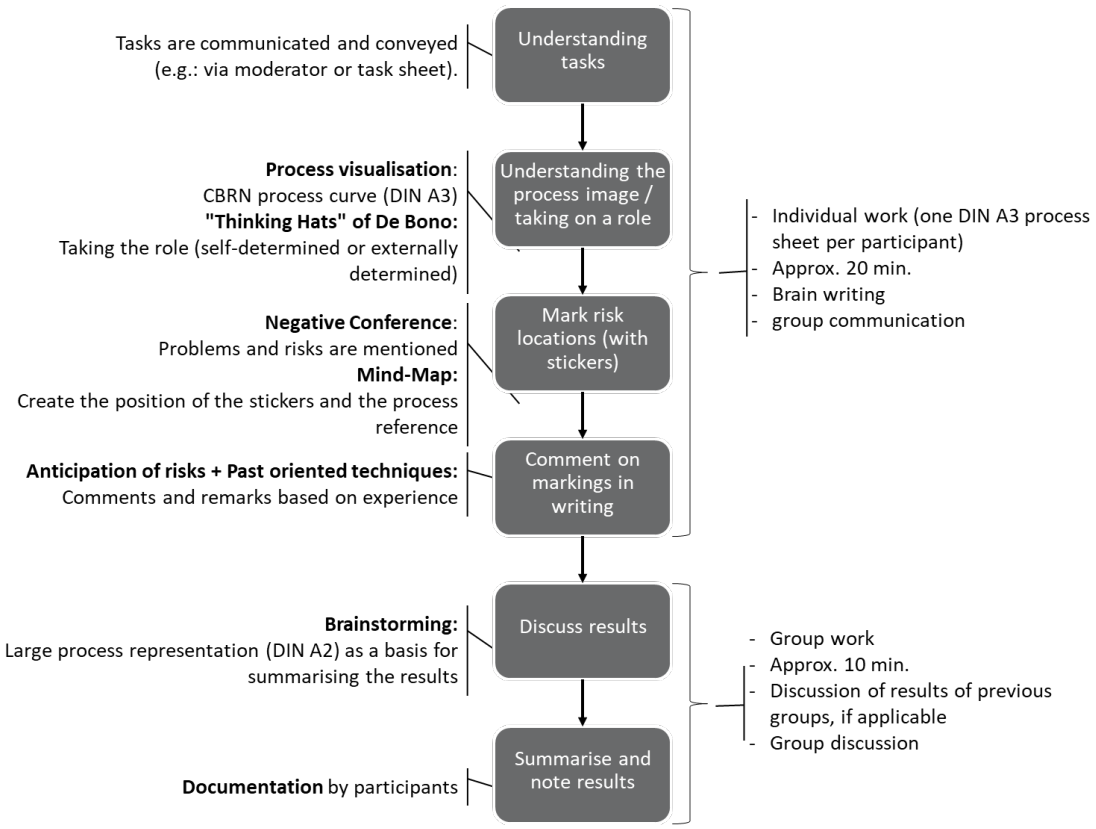


Figure 8: Workshop procedure

At the beginning, each participant received a DIN A3 image of the visualised CBRN process and stickers for the four technology types used in TOXI-triage as well as exclamation marks to label risk points. Participants provided some personal information and the perspective from which they viewed the process. In the following, the largest risk locations were to be marked and, if possible, commented on in their own process image for later evaluation. Following this 20-minute individual work phase, a 10-minute discussion was moderated in which the most important results of the table groups were summarised and noted on a DIN A2 process map. (Amelunxen *et al.*, 2018)

As a result of the workshop the used DIN A3 (A2) sheets with the process representation, the comments and stickers of the participants were available. The analysis of these sheets was divided into two parts for quantitative and qualitative results.

Quantitative evaluation and presentation of results

As a quantitative evaluation method, the number of stickers in each CBRN process step is counted and displayed in separate "heatmaps" (Figure 9). A heat map is a type of analysis that quantitatively visualises results and differences with colours. The results of the analysis should serve as preparation for further investigations and support the improvement of the CBRN process. For each sticker type and each subgroup, a heatmap is created and presented in relation to the segments of the CBRN process structure. The visual distinction of the meaning of a sticker ranges from red (highest number) to violet (lowest number). The following is an example of the heatmap of the risks over the rolls. For this purpose, 59 workshop sheets with a total of 620 stickers (138 risk adhesives) were evaluated. (Amelunxen *et al.*, 2018)

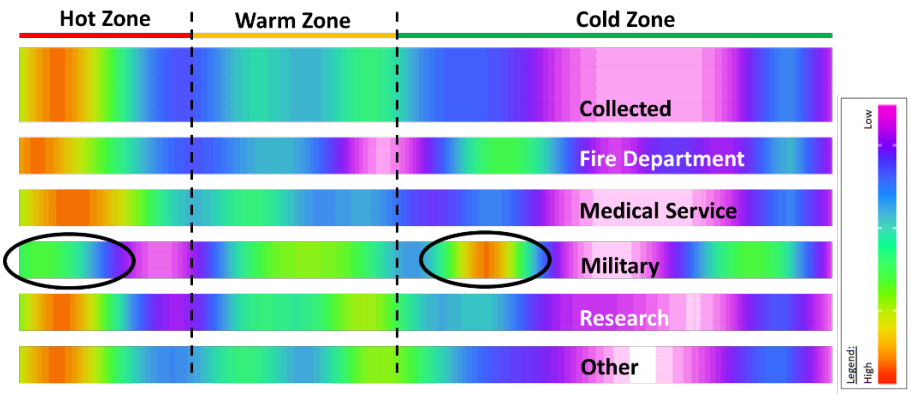


Figure 9. Extract: Risk-Heatmap with conspicuous deviations after rolls (Limper & Rammert, 2017)

This type of presentation allows conspicuous features, risk emphases per role or even deviations to be easily derived. In the following analyses, you can concentrate on these special points and analyse them more deeply. This 2D heatmap can be extended by another dimension. On another axis, for example, the probability of occurrence of the risk can be displayed. (Amelunxen *et al.*, 2018)

Qualitative evaluation and presentation of results

For the qualitative analysis of the workshop results, a concept was first developed to ensure that risk identification was completed and risk profiles or risk clusters listed at the end of this process.

The aim of risk identification is to obtain a list of all risks. For this purpose, the comments on the workshop forms were analysed according to the following procedure (Figure 10).

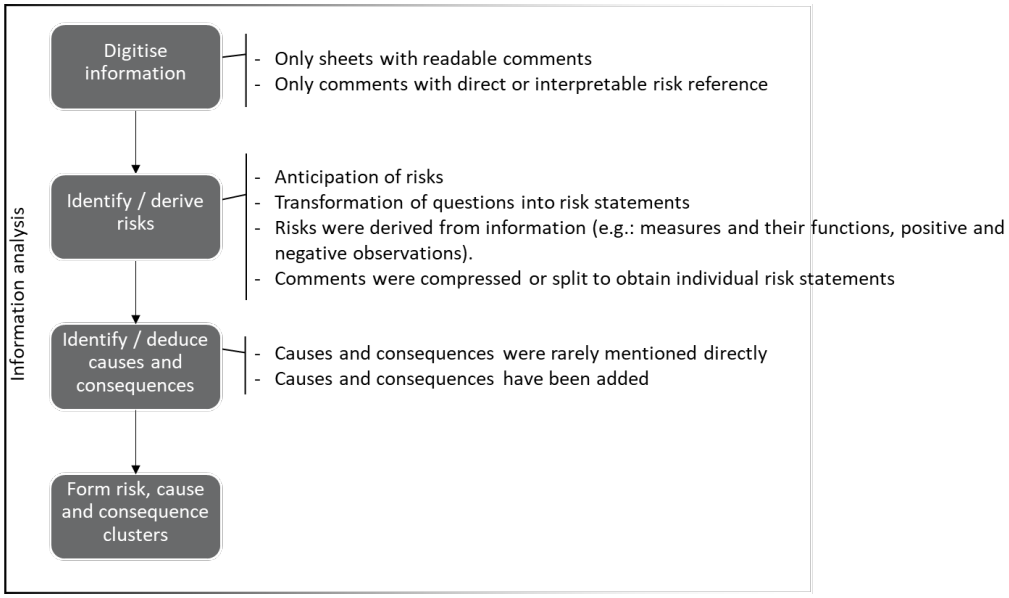


Figure 10. Procedure of qualitative information analysis

In a first step of *digitisation*, the readable comments with a direct or indirect reference to risks were recorded digitally and in written form. Questions were converted into risk statements and risks derived from measures. Long comments were compressed and divided into individual risks. There were 134 risks that were clustered (Figure 11).

Cluster analysis is a mathematical multivariant analysis. It can be assigned to the field of segmentation, which is defined as follows: The objects to be examined are combined into classes on the basis of similarities in the significant or important characteristics. When forming groups, *intuitive* or *formal* clustering can be used. In the intuitive clustering used here, the performing scientist uses his intuitive, non-explicit or explicable understanding of similarities. Greater objectivity is offered by the formal variant, which provides for a formal procedure. (Amelunxen *et al.*, 2018; Bradtke, 2003, p. 168; Eckes & Roßbach, 1980, p. 15)

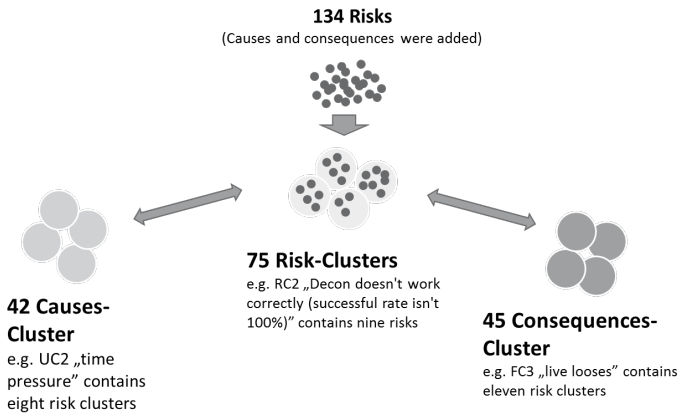


Figure 11. Procedure and results of the cluster analysis

The first cluster analysis bundled the risk descriptions and formed risk clusters. For many risks, these can be grouped into risk profiles (Austrian Standards, 2010, p. 11). These risk clusters correspond to the risk profiles defined in ISO 31000. All causes and consequences for the cluster have been collected and sorted according to the number of risks they contain. The risk clusters were then bundled according to cause or consequences and sorted according to the number of risk clusters contained. There were 42 cause clusters and 45 consequence clusters.

A large number of risks can be identified by the *risk identification* procedure. Depending on the level of detail of the analysis, a very complex system of cluster relationships emerges. This procedure promotes the understanding of the process solely on the basis of the execution of the analysis. Statements can be made about the probability of occurrence and the consequences based on the number of entries. (Amelunxen *et al.*, 2018) The biggest advantage is the optimal use of the available time of experts in the workshop. The time recording (Figure 12) of the qualitative risk identification carried out here shows that only a small part of the total time falls back on the experts.

Step		Time in hours	percentage
Process visualisation		35	55,1%
	Editing, visualisation, meetings, etc..: (several persons involved) >30h		
	Workshop Preparation >5h		
Information collection: **Expert w**orkshop (3 groups each 30 min.)		1,5	2,4%
Information analysis (qualitative result analysis)		27	42,5%
	Digitisation of diagram sheets 15h		
	Clustering 12h		
Total time requirement		63,5	100,0%

Figure 12: Time recording of qualitative analysis

OUTLOOK

The FTX[5] in TOXI-Triage is used for a second type of information collection. As Figure 7 already shows, the information is obtained via an observation sheet (Technology Evaluation Observers sheet), two questionnaires (End-User Evaluation of Usability and End User evaluation of technology aims) and the transcript of a debriefing (Post FTX Debrief open discussion).

The *information analysis* in FTX corresponds to the analysis from the workshop (Figure 10). In the second step of risk identification, a meta-analysis of the externally created questionnaires is also carried out. The questions indicate potential risks that the creators have identified in advance. Furthermore, the documents are first analysed

[5] TOXI-triage - FOCUS exercise, October 17, 2018, Athens (Greece); The FOCUS scenario simulated a chemical incident in an airport.

and all risk-relevant contents are listed. This includes the questions on the questionnaires and the comments of the observers. These include those that represent a direct or interpretable reference to risks.

A striking feature of the information analysis in comparison to the workshop is that causes and consequences are relatively frequently stated and the consequences outweigh them. In addition, risk statements can be made by naming causes (e.g. "Technology was observed many times scanning fluidly and easily despite glare and PPE being worn").

Preliminary results of the information analysis are 92 listed risks with a focus on technical risks. Risks are mentioned several times and overlaps with the identified risks of the workshop can be identified. What is striking here is that possible measures/solutions are also mentioned relatively frequently. The technical focus of the results can be traced back to the questions which correspond to the project objective of TOXI-Triage. The next step in the analysis of cluster formation has not yet been completed. Following the cluster analysis, the risks from the workshop and those of the FTX are compared. From this, conclusions are drawn on the applicability and their differences to the information collection.

Once the risk identification has been completed by the workshop and the FTX, a *risk analysis* can be carried out. The risk analysis analyses the causes and sources of risks. Various combinable analysis methods are used for risk analysis. These methods could be designed qualitatively, semi-quantitatively and quantitatively. Qualitative methods work with so-called significance levels such as "high", "medium" and "low" and require a clear legend. The semi-quantitative methods, on the other hand, worked with a numerical classification. For quantitative methods, estimated values are used. However, these methods are often not used due to a lack of information or the high effort involved. (Sander, 2018, p. 57; see DIN Deutsches Institut für Normung e.V., 2010, p. 11) Based on the risk management concept presented above (Figure 1), the methods are selected.

CONCLUSION

For the risk identification in the EU project "TOXI-Triage", a pictogram-based visualisation of the CBRN process, which was elaborated in detail, provided the basis for a resource-saving risk identification. In the current project, the first half of the risk identification process has already been completed with the collection of information through a workshop. Extensive and very complex interrelated risks were identified. At present, the first information collection by FTX has already been completed and the analysis is being carried out. A second information collection by FTX is currently in preparation. A concept for the risk analysis is currently being developed.

The presented concept shows the approaches for a holistic risk management in the area of emergency response. The focus here is on the integration and use of pictogram-based process visualisation. For risk identification and analysis, a high degree of methodological knowledge is sometimes required (Figure 13). This includes all methods presented. The advantage here lies in the good learnability, which does not require explicit process knowledge.

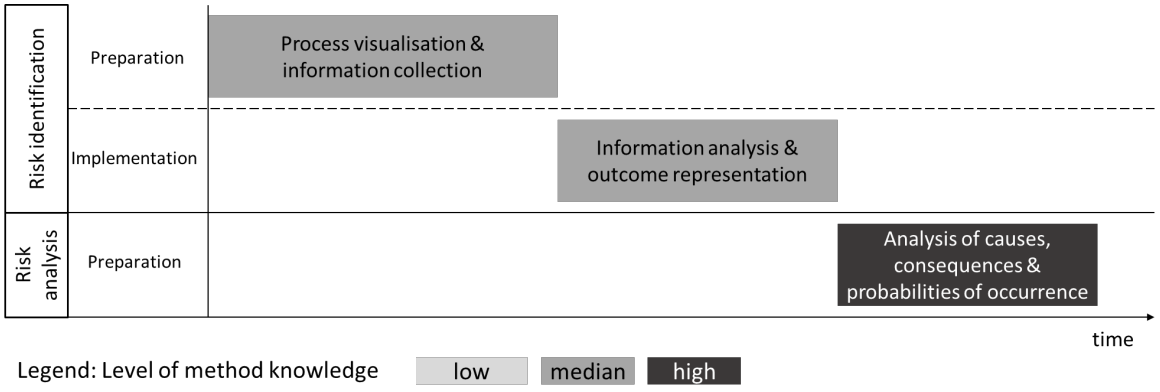


Figure 13. Resource needs of risk identification & -analysis – Resource "method knowledge"

The time intensive preparation of the risk identification with the elaboration of the process visualisation requires a low process knowledge (Figure 14). The resource "process knowledge" is only required to a large extent for the collection of information for a (very) short period of time. For the information analysis and the outcome presentation, medium or low process knowledge is sufficient. The depth of detail of the information analysis depends on the objectives of the following risk analysis. Due to the often complex dependencies on causes, risks and consequences, the need for resources can increase massively. The following risk analysis requires a high degree of methods knowledge and expert knowledge in order to gain detailed knowledge about the risks.

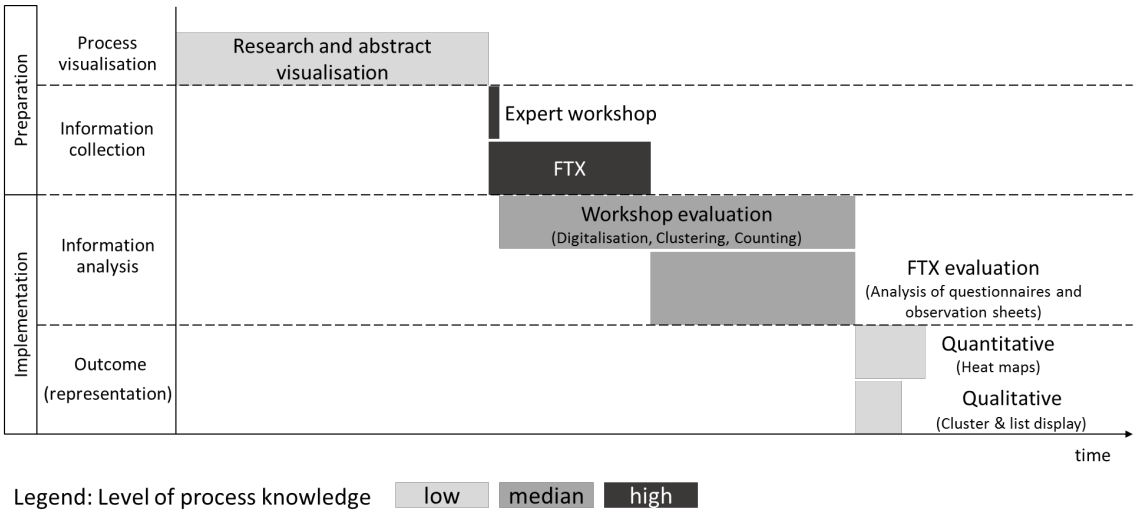


Figure 14. Resource needs of risk identification & -analysis – Resource "process knowledge"

The concept presented here shows a holistic concept, which is strongly characterised by the abstract process visualisation. The concept achieves good quantitative and qualitative results in a short "expert" time and can be flexibly applied to various questions/objectives. In addition, the information collection can also be integrated into project activities planned by third parties. The time available to experts is used highly efficiently. This is made possible by intensive preparation without the presence of experts. The further validation of the results is carried out against the results of the FTX.

A possible weakness of this method lies in the preparation phase. For the creation of the process visualisation sufficient information must be available, e.g. information about the considered object, the users and their knowledge as well as the goals. In the evaluation of the results, errors may occur in the interpretation of statements. These weaknesses can be counteracted by increasing resources and expert knowledge. . In the following it is also necessary to examine in which areas this type of process representation can additionally be applied and how or with which information systems it can be linked.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Union's Horizon 2020 (H2020) research and innovation programme under the Grant Agreement no 653409. ("TOXI-triage" project).

REFERENCES

Amelunxen, C., Rupp, N. & Sander, J. I. (2018) Methode zur Risikoidentifizierung in Prozessen der Gefahrenabwehr. In: *Mensch und Computer 2018: Workshopband*. Dachselt, R., Weber, G. (eds.).

Austrian Standards (2010) Risikomanagement - Grundsätze und Richtlinien (ISO 31000:2009). Austrian Standards, Wien.

Austrian Standards (2014) Risikomanagement für Organisationen und Systeme - Begriffe und Grundlagen - Umsetzung von ISO 31000 in die Praxis. Austrian Standards, Wien.

Becker, T; Prof. Dr.-Ing. Rainer Koch (supervisor) (2013) *Qualitätsmanagement in der zivilen Gefahrenabwehr Optimierung von Führungsprozessen durch interaktive SOPs*. DISSERTATION, Fakultät für Maschinenbau, Universität Paderborn, Paderborn.

BMI/BVA - Bundesministerium des Innern/Bundesverwaltungsamt (2018) *Handbuch für Organisationsuntersuchungen und Personalbedarfsermittlung* [WWW document]. URL http://www.orghandbuch.de/OHB/DE/ohb_pdf.pdf?__blob=publicationFile&v=25, accessed 21 February 2018.

Böhringer, J., Bühler, P. & Schlaich, P. (2011) *Kompendium der Mediengestaltung: Konzeption und Gestaltung für Digital- und Printmedien*. Springer, Dordrecht.

Bradtke, T. (2003) *Grundlagen in Operations Research für Ökonomen*. De Gruyter Oldenbourg, Berlin/Boston.

Densow, D., Demirdag, Y., Hädinger, T., Helms, E., Kay, M., Klausmann, C., Koch, M., Oesten, K., Özeker Mesut, Rall, M., Rieg, T. & Schwille, U. (2005) *Aufbau und Ablauf der Dekontamination und Notfallversorgung Verletzter bei Zwischenfällen mit chemischen Gefahrstoffen*. Deutschland. Bundesamt für

Bevölkerungsschutz und Katastrophenhilfe.
DIN Deutsches Institut für Normung e.V. (2010) Risikomanagement - Verfahren zur Risikobeurteilung DIN EN ISO 31010. Beuth Verlag, Berlin.
DIN Deutsches Institut für Normung e.V. (2015) Qualitätsmanagementsysteme - Grundlagen und Begriffe DIN EN ISO 9000. Beuth Verlag, Berlin, accessed 19 February 2018.
Eckes, T. & Roßbach, H. (1980) *Clusteranalysen*. Kohlhammer, Stuttgart.
Hasselbring, W. (1998) Erfahrungen mit dem Einsatz anwendungsspezifischer Piktogramme zur partizipativen Anforderungsanalyse. *Informatik - Forschung und Entwicklung*, **13** (4), 217–226. doi: 10.1007/s004500050114.
Herczeg, M. (2014) *Prozessführungssysteme: Sicherheitskritische Mensch-Maschine-Systeme und interaktive Medien zur Überwachung und Steuerung von Prozessen in Echtzeit*. De Gruyter Oldenbourg, München.
Herrmann, T. (2012) *Kreatives Prozessdesign: Konzepte und Methoden zur Integration von Prozessorganisation, Technik und Arbeitsgestaltung*. Springer Berlin Heidelberg, Berlin, Heidelberg.
Hofinger, G. (2013) Entscheiden in komplexen Situationen – Anforderungen und Fehler. In: *Entscheiden in kritischen Situationen: Neue Perspektiven und Erkenntnisse*. Heimann, R., Strohschneider, S., Schaub, H. (eds.), pp. 3–18. Verlag für Polizeiwissenschaft, Frankfurt.
ISO International Organization for Standardization (2009) Risk management - Principles and guidelines 03.100.01.
Kern, E.-M. & Hartung, T. (2013) Zielorientiertes Risikomanagement bei Einsatzorganisationen. In: *Kompetenz, Interdisziplinarität und Komplexität in der Betriebswirtschaftslehre: Festgabe für Klaus Bellmann zum 70. Geburtstag*. Kersten, W., Wittmann, J. (eds.), pp. 113–132. Springer Fachmedien Wiesbaden, Wiesbaden.
Limper, F. & Rammert, S; Koch, R. (supervisor), Amelunxen, C. (supervisor) & Rupp, N. (supervisor) (2017) *Concept creationn analysis and presentation of process analysis results through the example of a workshop implementation*. unpublished project work, Computeranwendung und Integration in Konstruktion und Planung (C.I.K.), Universität Paderborn, Paderborn.
Montag, N., Bausch, P., Sander, J., Max, D. & Kroll, R; Koch, R. (supervisor), Amelunxen, C. (supervisor) & Japs, A. M. (supervisor) (2017) *Conception of a Critical Incident Reporting System (CIRS) and quality management system on the example of fire brigades*. unpublished project work, Computeranwendung und Integration in Konstruktion und Planung (C.I.K.), Universität Paderborn, Paderborn.
Nöllke, M. (2015) *Kreativitätstechniken*. Haufe-Lexware GmbH & Co. KG, Freiburg.
Rittel, H. W. J. & Webber, M. M. (1973) Dilemmas in a general theory of planning. *Policy Sciences*, **4** (2), 155–169. doi: 10.1007/BF01405730.
Rupp, C. (2007) *Requirements-Engineering und -Management: Professionelle, iterative Anforderungsanalyse für die Praxis*. 4., aktualisierte und erw. Aufl. Hanser, München.
Sander, J. I; Koch, R. (supervisor), Pottebaum, J. (supervisor) & Amelunxen, C. (supervisor) (2018) *Analyse und Bewertung der Methoden und Bewertungskriterien zur Risikobeurteilung im standardisierten Risikomanagement*. unpublished thesis, Computeranwendung und Integration in Konstruktion und Planung (C.I.K.), Universität Paderborn, Paderborn.

The Design of a Mobile Application for Crowdsourcing in Disaster Risk Reduction

Quynh Nhu Nguyen
Links Foundation
quynhnhu.nguyen@linksfoundation.com

Antonella Frisiello
Links Foundation
antonella.frisiello@linksfoundation.com

Claudio Rossi
Links Foundation
claudio.rossi@linksfoundation.com

ABSTRACT

Disaster Risk Reduction is a complex field in which a huge amount of data is collected and processed every day in order to plan and run preparedness and response actions, which are required to get ready and to effectively respond to natural disasters when they strike. This paper, which targets a wide audience, focuses on the design of a mobile application that aims to integrate the crowdsourcing paradigm in current Disaster Risk Reduction processes. The design process is integrated in the User Centred Approach, which we apply through a co-design methodology involving end-users, iterative prototyping and development phases, and five in-field evaluations of the implemented solution. We describe both the design activities and the results obtained from end-users' feedbacks focusing on the perspective of first responders.

Keywords

Disaster Risk Reduction, Crowdsourcing, User Centred Design, Mobile Interface Design, Usability evaluation.

INTRODUCTION

The higher frequency and severity of natural hazards is increasing the complexity of all prevention and management activities. The whole set of methods, practices and activities aimed at preventing and reducing the impact of disaster, as well as managing their residual risks are referred as Disaster Risk Management and Reduction (DRR). DRR practices aim to reduce disaster risks also through a systematic data collection and analysis on disasters causal factors, which are used to orient a wise management of environmental and local resources so as to improve preparedness and response capabilities to future adverse events (UNISDR, 2009). DRR processes involve several organizations at various administrative and operational levels, each of which is equipped with specific ICT systems and services that serve different strategies and procedures. This implies a high complexity, also because local operational procedures vary a lot across administrative regions.

In this scenario, heterogeneous data are considered core enablers throughout all phases and functions of the DRR (Vieweg et al., 2010). The introduction of new ICT solutions able to collect and fuse data from multiple sources can have a positive impact on current operations and procedures, which could benefit from an improved data integration and management. Actionable data sources include remote sensed imagery, forecast models, environmental sensor networks, social media, and also novel mobile applications. In particular, social media platforms such as Twitter and Facebook are commonly used by citizens to collect and share unstructured information about incoming or ongoing crises. This represents a valuable opportunity for authoritative organizations, which could integrate such data into current DRR processes. Nevertheless, the cost to systematize, clean, sort and filter such unstructured and unreliable information flow makes the integration of crowdsourced data a very difficult task.

In this work we tackle this challenge, presenting the design of a novel mobile application (app) designed for integrating a crowdsourced data collection and validation activity into DRR procedures. The design process is integrated in the User Centred Approach, which we apply through a co-design methodology involving end-users,

iterative prototyping and development phases, and five in-field evaluations of the implemented solution.

Even though the app targets a wide audience, including citizens, this paper describes the design and the implementation of features dedicated to First Responders[1].

This paper is organized as follows. First, we review related works about the interplay between DRR and ICT solutions, focusing on the crowdsourcing approach and on the user centred/co-design frameworks. Next, we detail the overall methodology we followed and we briefly summarize the results from the co-design activities (Nguyen et al. 2017). Then, we describe the app design and we evaluate the usability of the implemented solution from ad hoc questionnaires. Finally, we present the conclusions and future works.

RELATED WORKS

During incoming and ongoing hazards, citizens generate and exchange a big amount of information. If properly filtered and processed, such data represent a great value that can enhance the situational awareness of both operation managers and first responders acting in the field. The most recent DRR approaches invite to take advantage of the direct participation of citizens (Abbasi et al., 2010). In critical conditions, people need to seek and share information, primarily to stay in contact with their family and community. Mobile technologies allow the fulfilment of these needs and can support the application of crowdsourcing approaches. Information access and sharing are two core features of the crowdsourcing, which is nowadays a consolidated socio-technical paradigm that mainly leverages on: (i) the willingness of people to actively contribute to actions of mutual interest (De Albuquerque, 2016) and (ii) the availability of current technology where services and applications running on mobile devices are able to gather and exchange geo-located information about a crisis (Kanhere, 2011; Littledyke, 2008).

The combination of social needs and technological capabilities allows the crowdsourcing to bring in-field data from the local up to the organizational level. Nevertheless, it exhibits some critical aspects. One of the most important issues is the information reliability, because crowdsourced data can be affected by from disinformation, false judgments, social biases (Guo et al., 2104; Ganti et al., 2011). Other relevant issues are data accuracy, sampling, temporal coverage and precise geo-localization, all of which are crucial for integrating crowdsourced data into DRR procedures. The ability of contributors to produce accurate data is considered a key aspect for applications supporting the environmental surveillance and the natural hazard prevention (De Longueville et al., 2010). Validation techniques are required to guarantee the reliability of the data collected from the crowd. They can leverage on automatic systems based on Artificial Intelligence as well as on human approaches where experts and/or peers have to manually perform the validation. Both approaches can benefit from the integration of reputation systems that dynamically rate contributors (Pennachiotti, 2011). Finally, crowdsourced data require tailored visualization techniques as well as specific skills for data analysis and interpretation within emergency organizations willing to include them in their procedures.

A mobile application for crowdsourcing data collection and validation activities within DRR operations shall be envisaged as a tool enabling new forms of cooperation between local agencies and citizens without disrupting existing procedures. The knowledge of the operational context, of the end-user organization and procedures is essential for the mobile application design, which must define functionalities, interactions and interface characteristics. A deep knowledge of the destination context and an exhaustive understanding of the end-users needs, skills, culture, and context are core concepts of the User-Centred Design (UCD) approach (Norman et al., 1986). The UCD is a methodology that entails several tools and techniques to systematically collect and use qualitative and quantitative data, which are used throughout the design and development process. Among the UCD methods, *the participatory design (or co-design)* focuses on collaborative practices that actively involve stakeholders and end-users onto the design challenge. Note that the co-design implementation requires a careful planning and a wide understanding of target domain. In co-design method, participants are considered as designers (Stepanek, 2015), stimulating the dialogue on a common problem and on possible solutions that can evolve in prototypes or shared artefacts. Through dedicated techniques, the co-design allows non-designers to articulate design proposals as a useful starting point for further professional developments (Sanders et al., 2010). The collaborative design activities allow to widen the design team's vision and develop a situated knowledge of complex domains. Moreover, the engagement of end-users helps in the design of usable (effective, efficient and satisfying) solutions.

We consider all the aforementioned issues to design and implement a novel app for crowdsourcing data collection and validation activities for DRR.

[1] The features specifically dedicated to citizens are presented in our previous paper (Frisiello et al. 2017).

METHODOLOGY

In order to collect a deep knowledge of the user needs and to set the context of in-field data collection activities, we followed the co-design methodology described in (Nguyen et al., 2017) involving representatives of the DRR ecosystem, namely emergency operation managers, field agents, volunteers and domain experts. The co-design process included: (i) an online survey aimed to map the expertise, interests and needs of the participants; (ii) an intensive co-design workshop (two full days) supported by a dedicated toolkit that has been designed to guide the workshop activities and at the same time to systematically collect information; (iii) the analysis of the data collected to extract end-user requirements for the mobile app design and development. Both functional and non-functional end-users' requirements have been derived from co-design workshop, while the information collected on the organizational level has provided relevant hints to define the user's profiles to be implemented in the app and the related permissions in compliance with the real processes and roles. Finally, the specifications on the content architecture (functions and information) and the interaction patterns have been defined, and then prototyped at levels of fidelity, first wireframes and then mock-ups. The mock-ups have been created using as much as possible elements from the Material UI library, which contains a large set of UI components ready to use and already familiar to end-users because commonly adopted in all views of the Android system

The participatory approach has been applied along the whole process, including the user evaluation activities. In order to validate intermediate versions of the mobile app, five demonstrations and user feedback sessions have been conducted in five different countries (Croatia, Italy, UK, Spain, Finland) involving end-users in real context. The evaluation procedure applied is hybrid: it combines the data collection from in-device usage in real context and from post-task surveys via: (i) the System Usability Scale (SUS) (Brooke, 1996) to evaluate usability, regardless of the different stages of maturity of the solution (Muddimer, 2012); (ii) the Net Promoter Score (NPS) as indicator of the perceived maturity of the solution on the base of a ten-score scale (Reichheld, 2003); (iii) a set of ad-hoc questions to investigate specific aspects of the app, such as the visualization layout, readability, procedures sequences.

CO-DESIGN RESULTS

The co-design workshop provided detailed indications about the types of data needed in each DRR phase, the expected flow of information and the applicable roles and related permissions, as well as on the information flows and graphic user interface (GUI) (Linux Information Project, 2004) design. It resulted that the crowdsourcing is positively seen as an opportunity to integrate data from the field and to improve the environmental surveillance. This capability is considered particularly useful during the response phase, in which contextual data can provide a deeper situational awareness of hazardous factors and can support decision-making processes. Hazard related data, together with indications of damaged infrastructures and resources availability, are the most relevant ones. Additionally, the provided information must be linked with the identification of the reporter, i.e., the person who provided the information, whom should be classified according to its role (e.g. citizen, professional in order to acknowledge reliable data. It resulted that volunteers are considered as trustable as a professional, while citizens cannot be equally considered. These considerations have been taken into account in the app design to create a role-based role visualization and to differentiate the data collection as well the validation procedures.

The visual prototypes produced highlighted two equally important information flows: an informative data flow, from the system to the mobile app, and a generative data flow, from the app to the system. The first flow is initiated by the authorities and includes: (i) alerts to the field, (ii) geolocated data (e.g. hazard and risk forecasts). The second flow is centred on the crowdsourced data generated in the field via mobile devices and geographically shared with the neighbouring community as well as with control centres managed by the authorities. These capabilities bridge a gap between Decision Makers sitting at control room sand in-field agents.

The co-designed artefacts suggesting an almost univocal content architecture, which we translated into a visual layout placing the authoritative informative level on the upper part of the screen and the crowdsourcing functionalities in the lower section. Furthermore, we translated the data collected in high-level guidelines for the app design, namely modularity, context-sensitiveness and reliability. They are defined as follows:

- *Modularity*: the DRR processes includes several processes, scenarios and target users. The key approach to handle this level of complexity is the modularity, i.e., the possibility to selectively provide and activate functionalities to different organizations. By avoiding the 'one solution for all' approach, a crowdsourcing solution can be integrated within existing systems and regulations.
- *Context sensitiveness:* the co-design phase showed that understanding the context is a top priority for emergency organizations, especially in the Response phase. First responders expect a context awareness tool able to support field operations providing additional data. They consider reliable the data coming from the system and, at the same time, they are willing to send data back from the field. This bidirectional

communication flow can enhance the effectiveness of in-field operations, especially when tight time constraints exacerbates stress condition.

- *Reliability*: trustworthiness is key to establish an effective data exchange. Therefore, the data produced by the crowd must be validated in order to be accountable. This requires a specific and distributed validation tasks to be designed within the mobile app. Interestingly, participants indicated that data sorting would let to quick spot relevant information, easing the validation task.

All these guidelines have been fully considered in the design of the mobile app.

THE MOBILE APP DESIGN AND PROTOTYPING

In this section we describe the design of the app[2], which we organize in paragraphs following a top down approach, starting from the *Access* (login and home screen) and then detailing the main informative sections. First, we explain the *Map & Forecast* section, which visualizes map *Layers* and other *location-based contents* on the map, then we describe the *Communication* and the *Social Media* sections, which shows the communications from authorities (*Warnings* and *Report Requests)* and the content extracted from Twitter, respectively. *Report Requests* allows authorities to request a targeted in-field data collection activity from app users, selected by their role. Finally, we present the *reporting* (*Do Report*) and the *validation* procedures. In each paragraph we include both the textual description and the corresponding visual representation of the explained functionalities. *Technical choices*.

Access: to use the app, an active account is required. Professional users are assigned to a given organization units and can have several roles among: 'Decision Maker' (people working in the control room), 'Organization Responsible' (the responsible of the organization with respect to the app) and 'In-field agent' (people operating in the field). The Home (**Figure 1**, right), which appears after the Login (**Figure 1**, left), allows to access the main app informative sections, which are placed in the upper half of the screen, namely: '*Map & Forecast'*, '*Communications'*, '*Review'* and '*Social'*. In the lower half there are two other sections, namely '*Settings'* and '*Help'*. The 'Settings' section allows to set user preferences about the language, the base map style, the *time window* and a *distance* in kilometers. Note that all information in the app are retrieved according to a given temporal interval, identified by the *time window*, and to a geographical area, i.e. the Area Of Interest (AOI), which is computed as the bounding box that inscribes the circle having as center the user position and as radius the *distance* specified by the user. The 'Help' section provides supports for newcomers, presenting a quick tour of the app. Finally, the bottom area is dedicated to specific call-to-action buttons: the 'Do Report' and the 'Report Request'. Their procedures are described in the '*Do Report'* and *'Report Request'* subparagraphs.

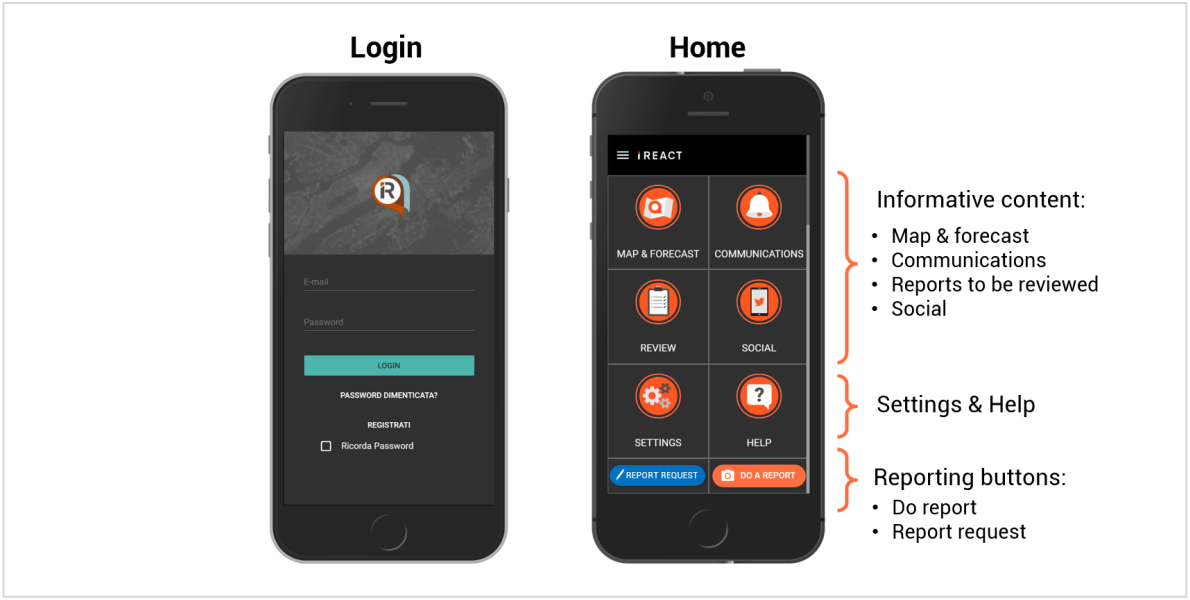


Figure 1 - Login (left) and Home (right) of the app.

Map & Forecast: location-based contents are made available in two different views: on the Map as color-coded pins and on a list-view. The Map enables a georeferenced overview of the current situation within the user's AOI.

[2] The app is named I-REACT

Every content available in the app (both incoming and outgoing information) is geo-localized and includes either a timestamp or a validity period. On the Map view, the user can pan and zoom the map. As the zoom level increases (zoom out) the pins are clustered in circles, where the center of the circles shows the number of the clustered elements and the circumference is proportionally colored according to the types of the clustered elements. The user can also click on a pin/pin cluster. If a pin is clicked, the map is centered on that pin and its informative card, which provides essential information about the pin, appears in the top part of the map. To access the full detail (Detail view) of a location-based content, the use must click on its card. If a pin cluster is clicked, the map is zoomed to that cluster until the cluster breaks into its sub-elements, which can be single pins or other clusters. This is a standard behavior and it is available in many other apps. In compliance with the co-design outputs, the main map controls are placed in the screen area reachable with the thumb (bottom part of the screen), which is known to be the most accessible (Hoober and Berkman, 2011). The bottom right controls let to center the map on the user position and start the report-creation procedure, while the left control lets the user to select the map layer to be visualized. A 'Compass' place in the top right portion of the map completes the set of controls. (Figure 2)

Given the very large amount of information potentially available on the app, the Map shows data solely on the user AOI (dotted line) and within the time window (showed in the green bar). In the app, all the spatiotemporal filters are editable from the Settings at any time.

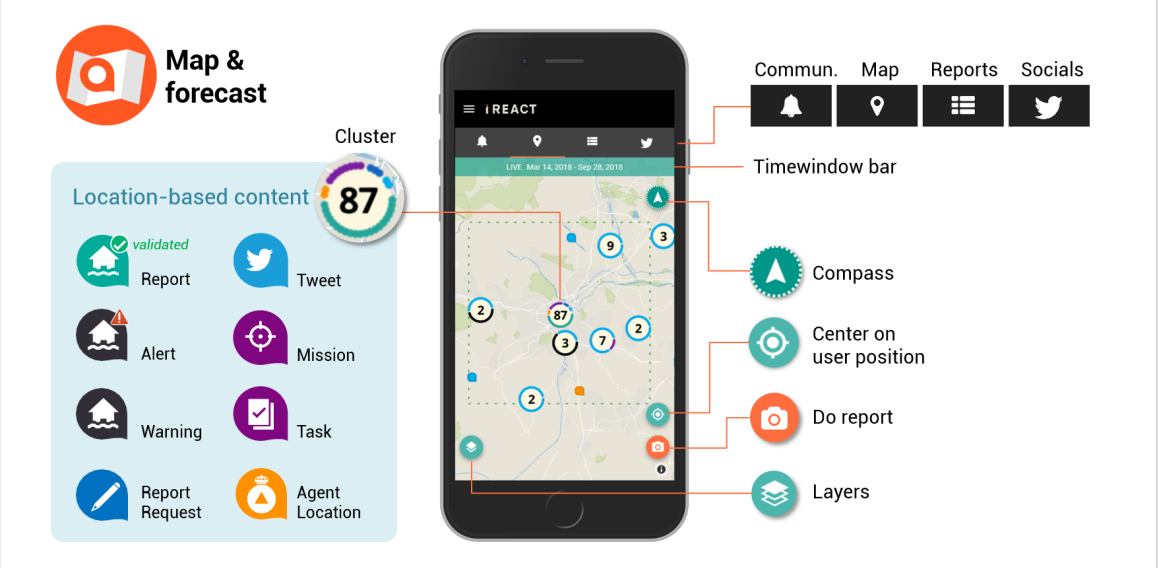


Figure 2 –Map & Forecast view: location-based contents visualized on the map together with map controls.

Layers. From the 'Layer' the user can select a map layer to be visualized on the map, one at a time. The detailed list of map layers available in the app, e.g. meteorological forecasts, is omitted for brevity. When a layer is activated, the app visualizes it on the map, enabling also the Legend button and the Player widget. The former allows to show the legend of the layer containing the association between the color and the values/classes of the layer data, while the latter enables the visualization of the temporal of the evolution of the selected layer, if any (Figure 3 shows an example of a temperature forecast). From the Player widget it is also possible to read the layer metadata.

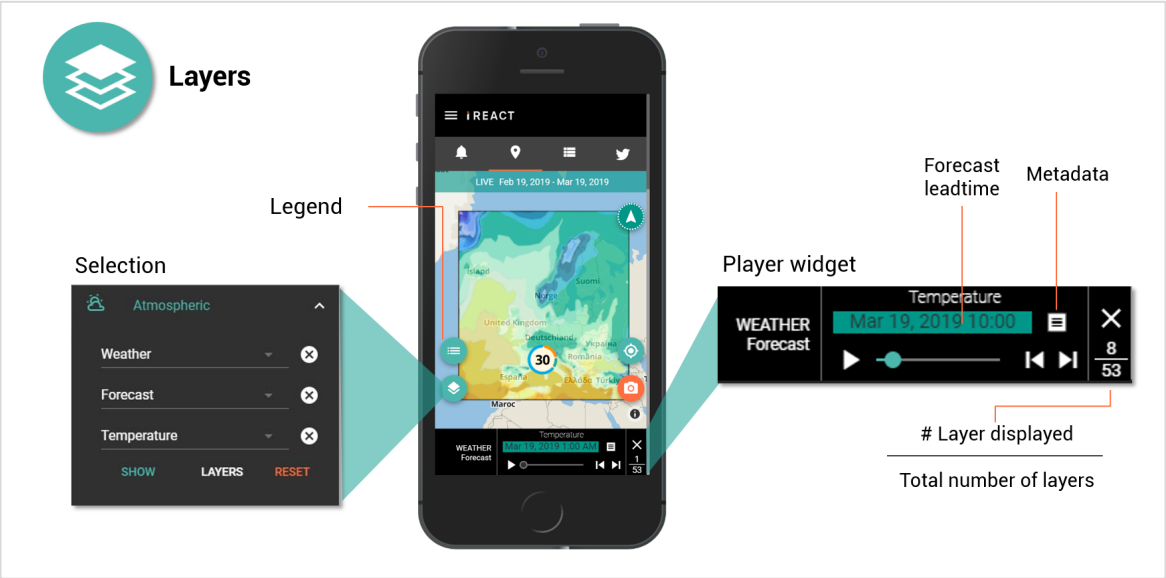


Figure 3 – Map view of a forecast layer (temperature): Layer selection (left), map view (center), player widget (right).

Communications: messages regarding Warnings (Alerts) and Report Requests coming from an authority or other trustable source (e.g. weather bulletins from regional/national authorities) are shown in this section (**Figure 4**). Warnings comply with the Common Alerting Protocol (CAP) (Standard, O. A. S. I. S., 2010), which is a standard format enabling the interoperability and the integration of alerts coming from different sources. Note that report requests are received by the in-field agents according to their location and the AOI specified by the sender. The request accomplishment is not mandatory, while the report request creation procedure is simplified as much as possible by a pre-selection of the requested parameters. The Communciation List view is omitted from brevity as it is very similar to the Report List views shown in **Figure 5** and **Figure 7**.

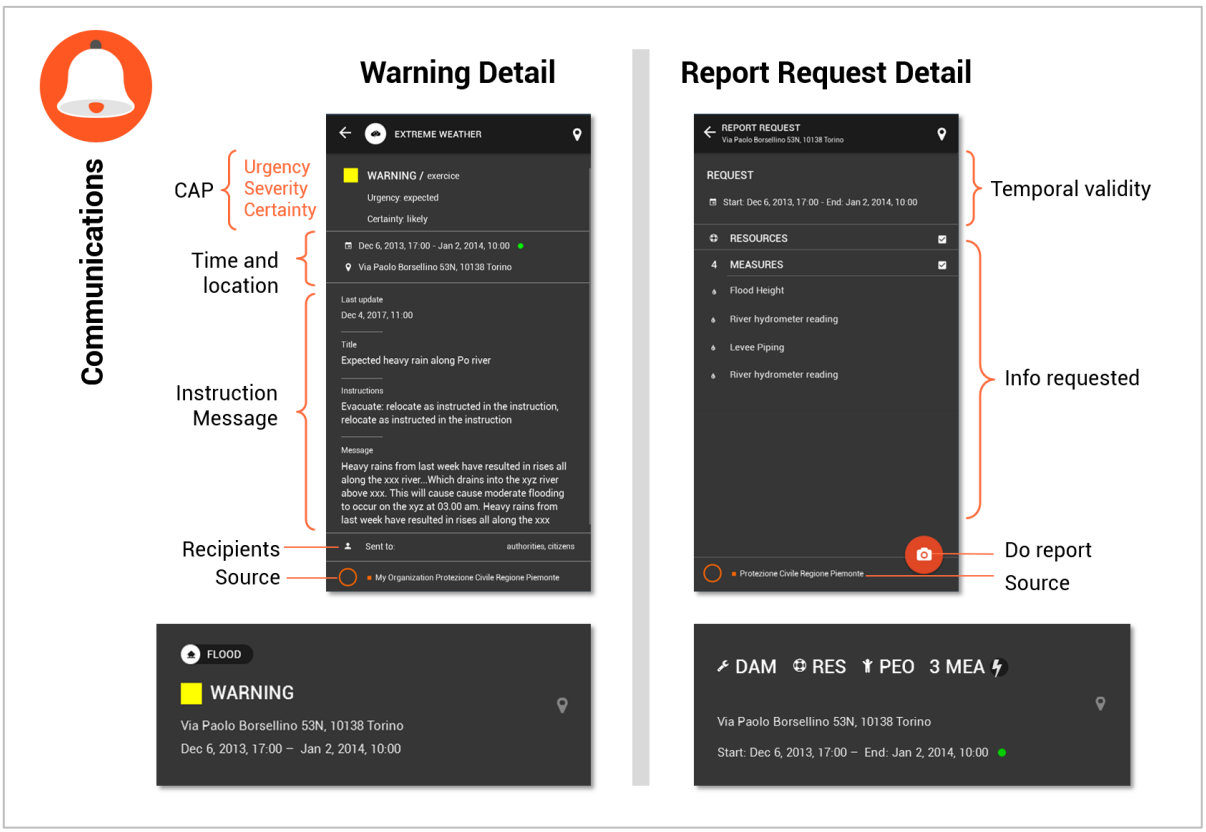


Figure 4 - 'Warning' (left) and 'Report Request' (right): card (bottom) and Detail (top) elements.

Social Media: this view displays automatically extracted hazard-related Tweets according to the user selection (**Figure 5**). The algorithm to extract and classify hazard related tweets is outside the scopes of this paper and it is detailed in Rossi et al. 2018. In the List view, quick filters allow to select the language, the time range, and the time sorting. Each extracted Tweets is also automatically classified with a set of labels, and the app allows users to give feedbacks in order to confirm or modify the automatic classification, which is structured into: named locations, hazards, information type (Affected Individuals, Caution and Advice, Donations, Emotional Support, Infrastructures, Volunteering), Informativeness (yes /no values), Panic (yes /no values). When Tweets are edited by a Professional, his/her feedback is considered as a validation, and the assigned labels are visible to all users, including citizens. If the feedback is given by a citizen, the system records it without propagating the user classification to other users. After a validation, no further amendments are allowed. All feedbacks contribute to iteratively improve the accuracy of the classification algorithm.

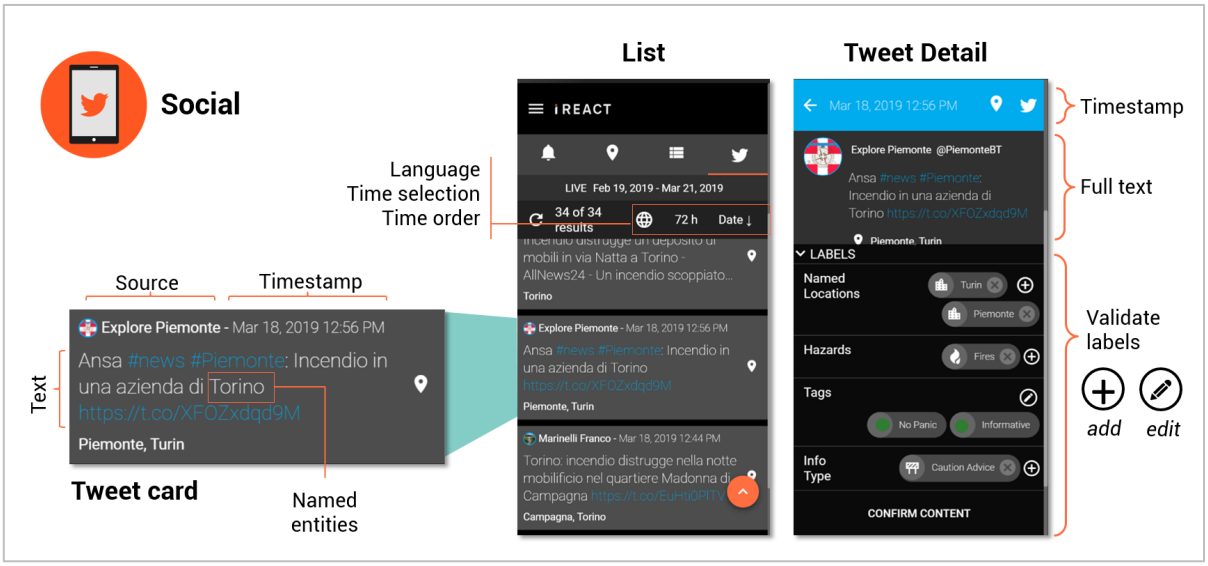


Figure 5 – Social media information: Tweet card (left), List (center) and Detail (right).

'Do Report' and report validation: being the collection of data from the field (Reports) the main activity supported by the app, the Do Report call-to-action has been included both in the Home and in the Map View. The report creation is a guided procedure in five steps: 1. Picture capturing; 2. Geo-localization; 3. Hazard description; 4. Information category; 5. Information details (**Figure 6**). The structured sequence replies to the need of having a pre-categorized and systematic data collection, and of minimizing typing errors, which are very common when free text inputs are used. The reporting procedure starts from the photo, since it has been indicated by organizations as the best format to quickly understand the situation described. Then, the geo-localization is acquired either through the device position (GPS) or with a manual selection of a point in the map. The latter possibility has been added to allow the reporter to stay at a safety distance from the hazardous point while doing the Report. A Report can include both quantitative and qualitative measures, which has been mapped using standard scales (e.g. Beaufort scale for wind velocity) when possible. The report form presents dynamically the set of measurement suitable according to the selected hazard, if any. Besides 'Measurements' it is also possible to report the presence of 'Damages', 'Resources' or 'People' by a multiple selection among listed items. These lists have been created after benchmarking multiple categorization across different emergencies organizations since a unique standard is not available and there is a great variability on the base of the hazard (e.g. water can assume opposite value whether there is a flood or a fire). The description of the report information categories is detailed in Frisiello et al. 2017.

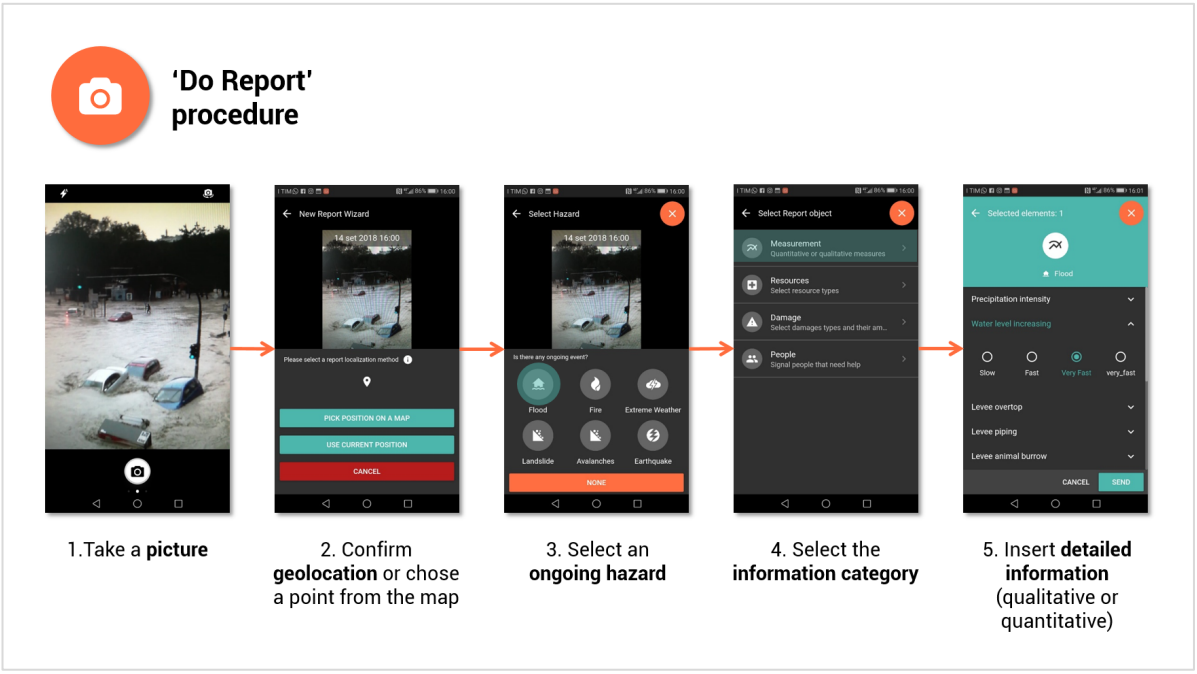


Figure 6 - Report creation procedure made of five different steps.

The report validation works at two different levels: citizens can peer-review other citizen reports by upvoting or downvoting, while specific professional roles, namely 'Decision Makers' and'Organization Responsibles', can validate/reject citizens' reports. All reports formats (Card and Detail) show a counter with upvotes and downvotes received by other citizens in the form of thumbs-up and down icons. The validation of a report is allowed only when consulting the Report Detail since a detailed evaluation is required (**Figure 7**).

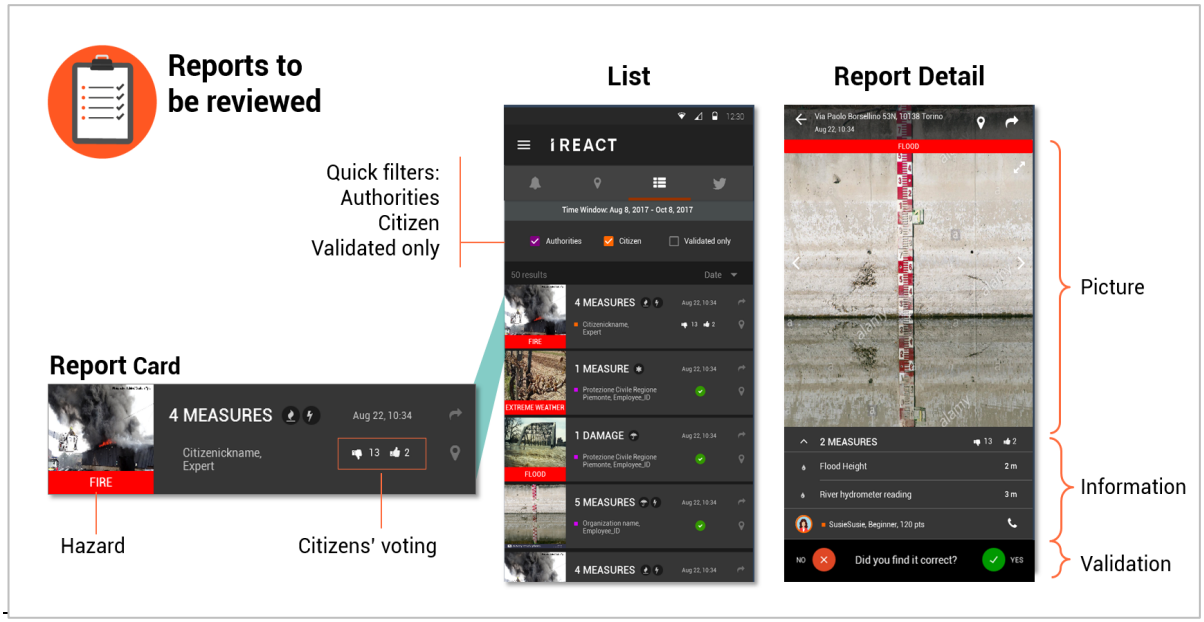


Figure 7 – Reports to be reviewed: Report card (left), List (center), and Report Detail (right).

USERS' EVALUATION RESULTS

The functionalities of the app have been implemented progressively and iterative user tests have been carried out to assess the app usability from the first responder's perspective. Over two-years, four training and simulations sessions in different European Countries (Sava Basin in Croatia, Cataluña in Spain and Helsinki in Finland) and one large scale exercise run by diverse European Civil Protections gathered in Italy have been the stages for the mobile app testing in the field. Realistic flood and fire disaster scenarios have been simulated envisaging the usage of the app, and immediately afterwards a feedback questionnaire was distributed to be filled online or on paper. 51 valid questionnaires have been collected from experts, professionals and volunteers from Public

Administration, emergency and environmental organizations at local, national and European level. The sample composition is heterogeneous per gender (27% female, 69% male, 4% not specified) and age (29% age: 25-35; 55% age: 35-55, and 16% over 56). In the following subchapters, we present the overall evaluation computed through the questionnaire as well as some comments received, which we structure according to the main app functionalities.

Overall evaluation

The overall satisfaction of the users has been computed after through the System Usability Scale (SUS), which has been derived from 10 questions exploring several features, including the ease of use, the experienced difficulty, the acceptance and the appropriateness for the tested app functionalities. The SUS output ranges from 0 (minimum) to 100 (maximum). The app received an average level of satisfaction (average SUS score of 62 in Table 1), which is slightly below the average according to the definition in (Sauro, J., 2011). It must be noted that the SUS is determined by several factors, including the level of a-priori experience, which generally results in an increase of SUS between 6% -15% (Muddimmer et al., 2012).

Table 1 - SUS overall scores

Min	37.5
Max	87.5
Average	62

Analyzing the replies on the single SUS variables, evaluated on a 5-points scale (1 very poor, 5 very good), it is possible to see that the integration of different data is the strength point of the app (Table 2).

Table 2 - SUS average per item

Item	Average
1 intention to use	3.6
2 complexity	2.6
3 easy to use	3.5
4 need of support	2.7
5 integration	3.8
6 inconsistency	2.3
7 desirability	3.4
8 cumbersome use	2.5
9 confidence	3.3
10 learning	2.7

The NPS, asking people to what extent they will recommend the app to others, confirms the positive attitude to use the proposed solution, in line with the SUS variable '1-intention to use'. The overall NPS scores computed across all demonstration is 6.8/10, while the NPS of the SAVA demo (the first one) and of the the Finnish demo (the last one) are 5.3/10 and 8.3/10, respectively. This is linked with the fine-tunings that have been made after each demo in order to improve the usability if the app functionalities. Therefore, most of the participants would recommend the app to other organizations. Some positive comments pointed out the good integration capabilities of the app and the possibility to engage citizens in the emergency procedures. Looking at other indicators, the full list of which is omitted for brevity, it resulted that users consider the app worthy (mean 3.9/5) and innovative (mean 3.5/5). Moreover, the graphic design is particularly appreciated (mean 3.9/5).

Ease of use of the main functionalities

Access. Enter the app results simple, but some crashes have been recorded and some delay was experienced in loading all the system information the first time. Therefore, adjustment have been made to improve performances reducing the bandwidth and memory requirements, e.g. the bounding box has been set to 50 km, which is enough to guarantee a good context awareness.

Navigation. The navigation structure is comprehensive and rich. It was appreciated that many phases of the emergency management cycle have been considered in the app design and in the content structure. Nevertheless, the information and the options presented are still too dense and users suggested some simplifications, e.g. reducing the layers categories and subcategories.

Settings. Time-window setting and layers activation are in general easy, with some negative comments o number of steps required in order to activate a map layer. Although a layer-button is present on the map, its findability is perceived as low. Changing the UI appearance (color and size) should be sufficient to highlight it. A further rationalization of the layer categories could make the selection and activation quicker.

*'Do report' and Report Request***.** Reporting have been tested in all demos in order to stress and evaluate the core functionality of the app. It has the highest success rate (87%) but also the high perception of difficulty (3.7/5) meaning that a training phase is needed to master the process and know the given options. The guided procedure has been appreciated but some comments were raised suggestion a simplified and shortened procedure, especially to target the general public. Another need would be to have a quick report option to send a simple geolocalized picture without content in very time constrained situations.

The *Report Request* works well, and it results very useful, but the scenario of reporting during an ongoing event might suffer the dependency of the system on the Internet connection. This is the weakest point of the app according to many users. The efficiency (effort spent, and number of steps required) is acceptable but it could be improved.

Validation. The procedure to validate reports is easy, it requires just a tap and hold on the proper button. Nevertheless, some details of the GUI could be improved. The used icons, designed to recall commonly known symbols, do not explicit well the specific types of actions available and their consequences. Reading the validation status of reports resulted very easy on both visualizations (map and list views).

Communications (alerts/warnings). The possibility to receive alerts/warnings is very interesting and important for the context of application of the app. Nevertheless, the notification should last longer when the app is in foreground as some comments claimed it disappeared too quickly. It is also difficulty to find the information after the notification. To improve this aspect the notification toast has been made permanent until the user selects one of these possible options: 'Close' to close or 'Ok' to go to the 'Detail' view of the alert/warning.

Social have been the last feature implemented and quite appreciated for context-awareness, with a slight preference for the map visualization that provides a geospatial overview (4.2/5) over the list browsing (3.9/5). The mechanism to provide feedbacks on the Tweet labels resulted not easy to do, but the GUI resulted clear, suggesting that an onboarding process could help to increase the social validation procedure.

In general, the organization of all functionalities have been appreciated with the need of simplification in some points, as the app is very rich in content. Comparing the two main information flows, the incoming data were quite clear to receive while the report creation showed a certain complexity of execution. Although the designed reporting has strutured the information exchange between the Decision Makers and the in-field agents, a certain degree of flexibility must be allowed to cope with emergency scenarios where it is better to have an incomplete report than not having it at all (for example only the picture with timestamp and position).

We observed pros as well as limitations of doing this kind of evaluation through simulated in-field demonstrations. On the one hand, we had the opportunity to test the app in the field and to immediately observe the app usage during a realistic operativity, involving simultaneously multiple users as it would be in a real emergency context. On the other hand, it was not possible to record video of the app usage. Another advantage of the simulated in-field demo is that it also allowed for informal talks with professional end-users. All the feedbacks were kept in the loop during the app fine tuning design, which entailed several revisions and feature improvements.

CONCLUSIONS AND FUTURE WORKS

The implementation of the co-design methodology based on the User-Centred Approach (Nguyen et al., 2017) resulted very effective to define key guidelines for the design of a crowdsourcing mobile solution for DRR scenarios and onboard the end-users from the very early stage of the design process. Regarding the iterative design, implementation and testing approach, we had the opportunity to use the demos to gather feedbacks that allowed to validate along the way the functionalities as they were released, distributing over time the changes and the management of the implementation complexity. The in-field demos confirmed that measures of onboarding were needed (both for professionals and citizens), which has been addressed by the 'Help' view integration in the final app to better explain the app functionalities to beginner users.

The main criticality seems to be the finding of the right balance between structured the procedures included in the the app so as to open the crowdsourcing to wide public while being integrated in existing emergency procedures

and systems. This suggests that group of citizens could have been engaged in the co-design together with DRR experts to collect complementary requirements.

Future works will be focused on the full implementation of functionalities for citizens. Among these, a gamification strategy for citizens (described in Frisiello et al. 2017) to increase citizens' awareness on natural hazards through educational contents and to foster citizen engagement is foreseen. The gamification strategy will allow to enroll citizens in structured data collection activities and features a solid validation criterion.

The app is called I-REACT and it is published on both the Android and Apple store. At present (15/02/2019) it counts 4.5k downloads from citizens.

ACKNOWLEDGMENTS

This work was partially funded by the European Commission through the I-REACT project (H2020-DRS-1-2015), grant agreement n.700256.

REFERENCES

Abbasi, A., Hossain, L., Hamra, J. and Owen, C. (2010) Social networks perspective of firefighters' adaptive behaviour and coordination among them, ACM International Conference on Cyber, Physical and Social Computing, pp. 819–824. Hangzhou, China.

Brooke, J. (1996) SUS - A Quick and Dirty Usability Scale, P. W. Jordan, B. Thomas, B. A. Weerdmeester, A. L. McClelland, Eds., Usability Evaluation in Industry, Taylor and Francis, London.

De Longueville, B., Luraschi, G., Smits, P., Peedell, S., & Groeve, T. D. (2010) Citizens as sensors for natural hazards: A VGI integration workflow. Geomatica, 64, pp. 41–59.

Frisiello, A., Nguyen, Q.N., Rossi, C., Dominici, F. (2017) Gamified Crowdsourcing for Disaster Risk Management. DSEM - Data Science for Emergency Management, IEEE BigData 2017, Boston, MA, USA.

Ganti, R.K., Ye, F. and Lei, H. (2011) Mobile Crowdsensing: Current State and Future Challenges. IEEE Communication Magazine, vol. 49, no. 11, pp. 32–39.

GUI. (2004) Linux Information Project. Retrieved from: http://www.linfo.org/gui.html (February 2019).

Guo, B., Yu, Z., Zhou, X. and Zhang, D. (2014) From Participatory Sensing to Mobile Crowd Sensing. IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops), Budapest, Hungary.

Hoober, S., Berkman, E. (2011) Designing Mobile Interfaces O'Reilly Media.

Kanhere, S.S. (2011) Participatory Sensing: Crowdsourcing Data from Mobile Smartphones in Urban Spaces. 12th IEEE International Conference on Mobile Data Management, Lulea, Sweden

Littledyke M. (2008) Science Education for Environmental Awareness: Approaches to Integrating Cognitive and Affective Domains. Environmental Education Research 14, pp. 1-17.

Muddimer, A., Peres, S. C., & McLellan, S. (2012) The effect of experience on System Usability Scale ratings. Journal of Usability Studies, 7(2), 56–67.

Nguyen, Q. N., Frisiello, A., Rossi, C. (2017) Co-design of a Crowdsourcing Solution for Disaster Risk Reduction, ACM Workshop on ICT Tools for Emergency Networks and DisastEr Relief (I-TENDER 2017), Co-located with ACM CoNEXT 2017, Korea.

Norman, D.A. & Draper, S.W. (1986) User centered system design: New perspectives on human-computer interaction. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Pennacchiotti, M. and Popescu, A.M. (2011) A Machine Learning Approach to Twitter User Classification. ICWSM, 11(1), pp. 281-288, Barcelona, Spain.

Reichheld, Frederick F. (2003) One Number You Need to Grow. Harvard Business Review

Sanders, E.B.-N. Brandt, E., Binder, T. (2008) A Framework for Organizing the Tools and Techniques of Participatory Design. PDC '10 Proceedings of the 11th Biennial Participatory Design Conference, pp. 195-198.

Sauro, J. (2011) SUStisfied? Little-Known System Usability Scale Facts. User Experience Magazine, 10(3). Retrieved from http://uxpamagazine.org/sustified/

Rossi, C., F. S. Acerbo, K. Ylinen, I. Juga, P. Nurmi, A. Bosca, F. Tarasconi, M. Cristoforetti, and A. Alikadic (2018), Early detection and information extraction for weather-induced floods using social media streams, International Journal of Disaster Risk Reduction.

Standard, O. A. S. I. S. (2010) Common Alerting Protocol Version 1.2. Available at: http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2.pdf

Stepanek, M. (2015) Building With, Not For. Stanford Social Innovation Review. Retrieved from: https://ssir.org/articles/entry/building_with_not_for (May, 2017).

UNISDR (2009) UNISDR Terminology on Disaster Risk Reduction. Available at: https://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf (January, 2019)

Vieweg, S., Hughes A.L., Starbird, K, et al. (2010) Microblogging during two natural hazards events: what Twitter may contribute to situational awareness. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ACM Press, pp.1079–1088.

Track 8.

Social Media in Crisis and Conflicts

Chairs

Starr Roxanne Hiltz, *New Jersey Institute of Technology, USA*

Amanda Lee Hughes, *Brigham Young University, USA*

Imran Muhammad, *Qatar Computing Research Institute, Qatar*

Christian Reuter, *Technische Universität Darmstadt, Germany*

Social Media Use in Emergencies of Citizens in the United Kingdom

Thomas Spielhofer & Anna Sophie Hahne
The Tavistock Institute, London
T.Spielhofer@TavInstitute.org, A.Hahne@TavInstitute.org

Christian Reuter[1] & Marc-André Kaufhold[1,2] & Stefka Schmid[1]
Science and Technology for Peace and Security (PEASEC), TU Darmstadt[1]
Institute for Information Systems, University of Siegen[2]
reuter@peasec.tu-darmstadt.de; kaufhold@peasec.tu-darmstadt.de

ABSTRACT

People use social media in various ways including looking for or sharing information during crises or emergencies (e.g. floods, storms, terrorist attacks). Few studies have focused on European citizens' perceptions, and just one has deployed a representative sample to examine this. This article presents the results of one of the first representative studies on this topic conducted in the United Kingdom. The study shows that around a third (34%) have used social media during an emergency and that such use is more widespread among younger people. In contrast, the main reasons for not using social media in an emergency include technological concerns and that the trustworthiness of social media content is doubtful. However, there is a growing trend towards increased use. The article deduces and explores implications of these findings, including problems potentially arising with more citizens sharing information on social media during emergencies and expecting a response.

Keywords

Emergencies; social media; Twitter; Facebook; representative study

1 INTRODUCTION

Interactive technologies play a major role in the context of peace and security (Reuter, 2019; Reuter et al., 2018b). This becomes obvious, recognising that social media is not only part of everyday life but is also increasingly used during emergencies or crisis situations (Reuter et al., 2018a; Reuter & Kaufhold, 2018). Our work tries to grasp exactly this specific scenario of social media usage, thereby following studies examining frequency of use of social media in situations of emergency. Relying on survey participants' answers, we chose to prioritise subjective perceptions of usage over numerical measuring of, for example, Tweets referring to a specific disaster. At the same time, focusing on subjective statements allows for an analysis of frequency and diversity of use, taking into account various sociodemographic factors. Furthermore, our study offers the possibility to establish an overview of the subjects' different reasons for social media use in emergencies.

Looking at the respondents' patterns of social media use in crises, we are also interested in their respective attitudes, not least with regards to their readiness to share data with emergency services or their assessment of social media as an effective means to look for and share information before, during, or after an emergency. Our research project EMERGENT, funded by the European Commission, involved conducting representative online surveys of citizens in the UK, Germany, the Netherlands and Italy. Here, presenting our case study, we focus solely on the results of British respondents. The case of the UK stands out because of its relative low frequency and diversity of use. This is not surprising because of the UK's image of an active emergency management and social media-friendly culture (Government, 2018; We Are Social, 2016). At the same time, the island is, like Italy and its history of earthquakes, rather prone to natural disasters (Lo & Chan, 2017; Salvati et al., 2014). Thus, we aim for a thorough understanding of the perceived behaviour of the British population, ground for action, and their subjective parameters for assessment of social media use in emergencies and emergency services' roles. As we are interested in the use and perception of social media determining factors, we looked for potential relationships between sociodemographic factors (age, gender, social grade) and ordinary social media use taking into account British respondents' perceptions on social media use in emergencies. In this article, we present the results of a

survey, involving 2,000 citizens living in the UK, conducted in October 2016. It is assumed that this allows for a more effective usage of social media and emergency applications during emergencies. We first aim for an understanding of different attitudes regarding social media usage in daily life, followed by focusing on individuals' assessment of use of respective channels in the context of emergency events. Third, we dedicate attention to use and evaluation of emergency apps, thereby assuming perceptions of such applications to be closely related to perceptions of social media use in times of emergencies. The presentation of results is succeeded by a discussion and concluding remarks.

2 BACKGROUND

During the last years, many studies on approaches for ICT in safety-critical environments, such as emergencies, have been published (Hendela et al., 2017; Hiltz & Plotnick, 2013; Starbird, 2017). They cover potentials of new technologies for safety-critical work (Norros et al., 2011), including the risk of information systems failures (Beynon-Davies, 1999). They also include approaches for coordination among emergency management units (Chen et al., 2008; Hill, 2010), support of awareness and team work (Carroll et al., 2006) and distributed collaborative situation-map making (Gunawan et al., 2011; Kogan et al., 2016). Other areas of research cover the design of emergency medical services (Kristensen et al., 2006), electronic documentation in medical settings (Sarcevic & Ferraro, 2017), and concerns against sensor-enhanced medical systems (Dahl et al., 2016). Newer approaches in emergency management work include the use and analysis of social media (Stieglitz et al., 2014). A review of the literature suggests that while there have been some quantitative studies exploring the attitudes of emergency services and citizens towards the use of social media in emergencies, there are only a few publications using representative samples to provide accurate estimates.

There are a few quantitative studies on authorities' perception of social media, and most are from North America. This includes one study (San et al., 2013) that analysed the results of a survey conducted in 2012 by the American National Emergency Management Association (NEMA). This survey asked staff members of emergency services from all 50 federal states of the US about social media use in emergency management. It found that most emergency services used social media to 'push information out to the community' during crises while lacking the skills and work force to access and analyse information shared by citizens on social media during such events. Additionally, mistrust of such information and lack of dedicated personnel to access such data were perceived as main barriers to more dedicated use of social media data. More recently, Plotnick et al. (2015) conducted a survey of 241 US emergency managers at county level in 2014 about usage patterns, barriers, and improvement recommendations for the use of social media during emergencies. It found that by 2014 only about half of these agencies used social media in any way and most did not have any formal policies to guide their use. Once again, the main barrier was found to be the lack of dedicated staff. Another survey that was conducted with English respondents further indicated a greater importance of political and organisational constraints (Shan et al., 2017). In contrast, the annual survey of the use of social media by IACP (International Association of Chiefs of Police, 2015) encompassing 553 law enforcement agencies, representing 44 states, found that 96.4% of agencies surveyed used social media in some capacity and that a very high proportion (85.5%) had used data from social media to solve crimes in their area. This could suggest either that social media use among emergency service is increasing or that police services place a much greater emphasis on it than other emergency services. Gray et al. (2017) examined Tweets in the context of three UK storms, and highlighted the importance of reducing information overload during multi-hazardous events, as well as demonstrating that sociodemographic factors could potentially influence social media usage during disasters.

There has only been one similar study conducted in Europe to date (Reuter et al., 2016), based on a survey of 2014 of 761 emergency service staff across European countries. It showed that in 2014 very few emergency services in Europe were using social media extensively; in particular, it was hardly ever used to receive information from the public. Thus, only 4% of survey participants indicated that they often receive messages from the public via social media during a crisis. While only 23% reported that they often use social media to gain situational awareness during emergencies, 46% said that they did at least occasionally.

Similarly, there are very few quantitative and recently published studies exploring citizens' attitudes towards using social media in emergencies. This includes a comparative study with over 1,000 participants conducted by the Canadian Red Cross (2012) and a similar survey by the American Red Cross (2012) involving 1,017 online and 1,018 telephone survey respondents. The latter found, for example, that around one-in-ten of the general population had used social media to find out or share information during an emergency. Furthermore, Flizikowski et al. (2014) conducted a survey with European citizens and public protection and disaster relief organisations (PPDRs) about perceptions and use of social media. Unfortunately, this was not based on a representative sample.

Reuter and Spielhofer (2017) conducted a similar survey, involving 1,034 citizens of the European Union. It found that while around two-in-five citizens had used social media to search for information in an emergency (43%),

only just around a quarter had used it to share information (27%). The survey also showed that 42% of citizens indicated that they would expect a response within an hour if they posted a request for help on an emergency service social media site and that 69% believed that emergency services should regularly monitor their social media channels to be able to respond immediately to such requests. An even more recent study, in 2016, was conducted by Reuter et al. (2017) in Germany. This representative study involved 1,069 citizens using an online-survey with similar questions regarding frequency and diversity of usage. The survey showed that nearly half (45%) of the respondents had used social media to share and/or look for information during an emergency, but only 16% had downloaded an emergency app. In contrast to these results, British and Northern Irish respondents showed lower percentages with respect to both questions.

However, apart from the survey conducted in Germany, there is a gap both in representative studies from across Europe (the study by Reuter and Spielhofer (2017) was based on an opportunity sample) and with respect to the UK and other European countries. In this paper, we focus on the UK as it poses an interesting case of relatively low frequency and interest of social media use during emergencies while it is suggested that ordinary social media use is comparatively at a medium level (We Are Social, 2016). There are various studies focusing on sociodemographic factors like age or gender with respect to social media use (Barker, 2009; Correa et al., 2010; Lin et al., 2014). Yet, our paper presents a first attempt to bring these variables together with ordinary social media use (Lev-On & Uziel, 2018), thereby trying to offer a bigger societal picture with respect to this specific scenario of social media usage.

3 RESEARCH DESIGN

The findings reported in this article are based on an online survey conducted by Opinium Research between 8th and 9th October 2016, with the research agency generating a diverse sample from a pool of volunteers. Respondents were offered a small allowance. The main goals of the survey were to explore UK adult citizens' (aged 18 or above) attitudes towards the use of social media for private, everyday life purposes and in emergency situations. It was conducted as part of a European project study. It consisted of nine sets of questions, most of them in closed-answer format, except for the last, open-ended, question. Questions addressed: (1) information about gender, age, social grade, working status and geographical location (UK region) of participants; (2) citizens' frequency of social media use; (3) their previous use of social media in emergencies to share or look for information; (4) if applicable, the types of information shared; (5) the expected responsiveness of emergency services to answer to messages posted via social media; (6) opinions about discouraging factors for using social media in emergencies; (7) the extent to which they had previously downloaded any smartphone app to be used in emergencies and, if so, what apps they had downloaded; (8) their expectations regarding the use of such apps in the future; (9) an open-ended question, asking them to provide further details about experiences with social media in emergencies.

A total of 2,000 UK citizens completed the survey, including 1,118 women (55.9%) and 882 men (44.1%). Most respondents (91.2%) were between 25 and 74 years old. Around two thirds of the respondents (66.6%) were in the social grade ABC1 and around one third (33.4%) in the social grade C2DE. These social grades refer to the classification system based on occupation and developed by the National Reader Survey (2019). Social grades A, B, and C1 are combined to represent middle and upper class, which therefore can be distinguished from C2, D, and E, representing working and lower class (Dobson, 2016). A large proportion of citizens (39.6%) were working full time and 25.3% were retired. Most respondents (83.1%) lived in England, especially in the South and East of England (33%). As there were significant differences between the respondents and population statistics, the sample was weighted to be representative of the population for the gender, age, social grade, working status and home region of respondents. This was done using the most recent population statistics (Office for National Statistics, 2017). The analysis is based on this weighted sample.

For the quantitative analysis, survey data was extracted and analysed using IBM SPSS Statistics 23. Microsoft Excel was used for the design of the displayed figures. The analysis consisted of three key steps: (1) preparing the data, including assignment of missing values and data values, and combination of categories of demographic background variables; (2) exploring basic frequencies for each question; (3) using cross-tabulations with chi-squared tests to explore any significant differences for different types of respondents in relation to gender, age, social class, region and working status. In addition to that, Mann-Whitney U Tests were used for ordinal variables and Kendall's Tau was used to determine correlations between ordinal items. Test results including effect sizes are displayed in brackets. Conventions for Cramer's V depend on the degrees of freedom (*df*). According to Cohen (1992), Cramer's V of .1 is regarded as small, Cramer's V of .3 as medium and Cramer's V of .5 as large, if df=1. For higher degrees of freedom, the required Cramer's V for the interpretation of small, medium and large effect sizes is smaller.

For the qualitative analysis, open responses from 1,958 respondents were coded using Microsoft Excel. This

involved thorough reading of all responses of the open-ended question and generating and validating key themes. These were then used to define categories and the open responses were repeatedly analysed collectively and assigned to one of the categories. Six categories were defined, encompassing scepticism, conditions, range of applications, productivity, inexperience, information flow. These were further categorised into assessed barriers (scepticism, conditions), advantages (productivity, information flow), and experience (range of applications, inexperience) regarding social media use in emergencies. The literature review and the quantitative analysis that was done beforehand helped to increase 'theoretical sensitivity' (Strauss, 1987) and establish the context of the qualitative analysis.

It also needs to be noted that the questionnaire did not define an emergency concept or situation, mainly to find patterns and similarities within individuals' own perceptions towards emergency situations. Situations of emergencies were thus defined by the individuals themselves.

Contrasting prior work focusing on bigger disasters (UN Office for Disaster Risk Reduction, 2016; Whittaker et al., 2015), we choose a broader definition (Haddow et al., 2002) of emergencies, referring not only to academically conceptualised emergencies and disasters but also emergency situations in which only a few individuals may be affected and call upon emergency services' standard procedures for help (e.g. burglary). This allows a glance at individual perceptions of incidents disrupting their everyday lives while otherwise not reaching the categorical threshold of an emergency with collective impact. Communication via social media may prove to be effective in each scenario. Aware that individual incidents differ in scope and individuals may pursue actions via social media differently, citizens may want to contact emergency services or have high expectations towards authorities independent from the type of emergency. We assume that a broad understanding of an emergency takes into consideration that various participants define emergencies based on their own experiences and conventional usage of the term, the common understanding forming the basis of individual action and defining circumstances at which social media may aim. In contrast to other studies focusing, e.g. only on perceptions of directly involved individuals, we defined individuals to use social media during emergencies even when they were not directly involved as primary sources of information as this may show interesting results as well.

4 FINDINGS

In the following, we present our results regarding ordinary social media and smartphone use, social media use in emergencies and the use of emergency applications. At the same time, we report correlations between sociodemographic factors and ordinary social media use, respectively, and the use of social media in crisis situations, potentially yielding both theoretical and practical implications.

4.1 Use of Smartphones and Social Media

The survey confirmed findings from other recent research in the UK (We Are Social, 2016) regarding the use of smartphones and social media usage. Table 1 below sets out the main findings from the UK survey carried out in October 2016.

Activity	Hourly	Daily	At least once a week but less than daily	Less than once a week	Never
Use a smartphone	30%	43%	6%	2%	19%
Use Facebook	11%	48%	12%	7%	21%
Use Twitter	4%	14%	9%	11%	62%
Use other types of SM	5%	19%	19%	18%	39%
Post messages on SM	3%	14%	21%	28%	34%

Table 1: Proportion of regular smartphone and social media users (N=2000)

It shows that over four-in-five adults in the UK currently use a smartphone at least occasionally while 19% never use one. Looking at these 19% more closely, it shows that they are most likely to be older and/or in the lowest social grade of the population. More specifically, those reporting not to use a smartphone are most likely to be:

- aged 75 or older: 49% of this age group do not use a smartphone, compared with 3% of 18-24-year-olds; among those aged 65 to 74, it is 37% (χ^2 (6, N=1999) = 232.97, p <.001, Cramer's V =.34).
- in the lowest social grade (E) of which 32% never use a smartphone; in contrast only 10% of those in the highest social grade (A) do not use one (χ^2 (5, N=2001) = 57.78, p <.001, Cramer's V =.17).

There was no difference depending on gender.

The analysis also shows that a very similar overall proportion of citizens use Facebook as there are smartphone users. But even though there is clearly some overlap of non-Facebook users with those who use a smartphone. Around half of those not using a smartphone still use Facebook. In total, around 9% of citizens neither use a smartphone nor Facebook.

Interestingly, even though young people are far more likely to be Facebook users, relatively high proportions of older people use it too (χ^2 (12, N=2000) = 138.03, p <.001, Cramer's V =.26). While 93% of 18-24-year-olds use it at least sometimes and 76% of those in this age category use it daily, 58% of those aged 75 or above use it occasionally or more and 39% on a daily basis. One other noticeable pattern is that there is virtually no difference between 18-24- and 25-34-year-olds in the proportion that uses Facebook on a daily basis.

The survey also showed that there is a significant difference in the use of Facebook depending on gender (χ^2 (2, N=2001) = 34.13, p <.001, Cramer's V =.13). Thus, 65% of women use Facebook on a daily basis, compared with 53% of men. Similarly, while 82% of women use Facebook at least sometimes, it is only just above three-quarters of men who do so. Adult citizens in social grades ABC1 were also slightly more likely to use Facebook (81%), compared with those in lower social grades C2DE (77%) (χ^2 (1, N=2000) = 4.73, p <.05, Cramer's V =.049). However, this could reflect the fact that 31% of those in the social grades C2DE are retired, compared with 21% of those in ABC1, potentially reflecting the older age group of those in the lower social grades above anything else.

Twitter is used by fewer people than Facebook in the UK. Thus, around one-in-five (18%) use it daily and 38% use it at least occasionally (less than once a week or more often). Once again, Twitter users are most likely to be young citizens: Fifty-three per cent of under 50 years use Twitter at least sometimes, compared with only 22% of those aged 50 or above (χ^2 (2, N=2000) = 224.94, p <.001, Cramer's V =.34). Daily Twitter use is at a peak among 18-24-year-olds (37%) and falls to just one per cent among those aged 75+ (χ^2 (12, N=1999) = 257.09, p <.001, Cramer's V =.36).

Looking at respondents who use Twitter on an hourly basis, the proportion is only relatively high (11%) among both 18-24- and 25-34-year-olds. For all other age groups, it is at three per cent (35-44-year-olds) or below. Another significant difference is that regular Twitter users are most likely to come from social grades ABC1 (χ^2 (2, N=2000) = 51.55, p <.001, Cramer's V =.16): Two-thirds (67%) of those who use Twitter daily are in these social grades. Thus, is that almost twice as many citizens in social grades ABC1 (23%) use Twitter on a daily basis, compared with those in social grades C2DE (13%).

Moreover, men are significantly more likely to use it on a daily basis (22%, including 6% using it on an hourly basis) than women (15%, including 2% using it hourly) (χ^2 (2, N=2000) = 19.30, p <.001, Cramer's V =.098).

4.2 Use of Social Media in Emergencies

While the majority of UK citizens (85%) use some form of social media at least occasionally, considerably fewer citizens have used social media during an emergency. More specifically, around one third of the survey sample (34%) indicated to have used some form of social media in the past to look for or share information during an emergency, such as an accident, power cut, severe weather, flood or earthquake (**¡Error! No se encuentra el origen de la referencia.**). This includes 21% who used it to share information and 13% who used social media to find information only. It is worth noting that those participants that have not used it may not have had the need to do so as they may not have experienced an emergency.

These results are reflected in responses to an open-ended question in the survey, asking participants to provide fuller details about their use of social media in emergencies. This included respondents who stated that they either do not use social media at all or have never used it during an emergency. Others highlighted the way social media was a useful tool to send and receive up-to-date information very quickly:

> *'Social media is often the most effective way of finding out about incidents quickly'.*

> *'It's a very easy and convenient way to reach a lot of people all at once! Information spreads quickly on social media and is more likely to be seen by a large audience. If there was a national or even worldwide emergency, it would be one of the best ways of quickly sharing important information with everyone.'*

Specific uses of social media included looking for information shared by emergency services or news agencies, using it to share or look for transport disruption details, and for sharing information about the emergency, or that you are safe, with friends and family:

> *'When being stranded in Europe due to ash cloud I have shared pictures of queues at airport on Facebook.*

Used Twitter feed for latest information on closures and shared my location with colleagues also trying to get home.'

'It's good to warn friends of things or to let people know you are safe without contacting each one individually.'

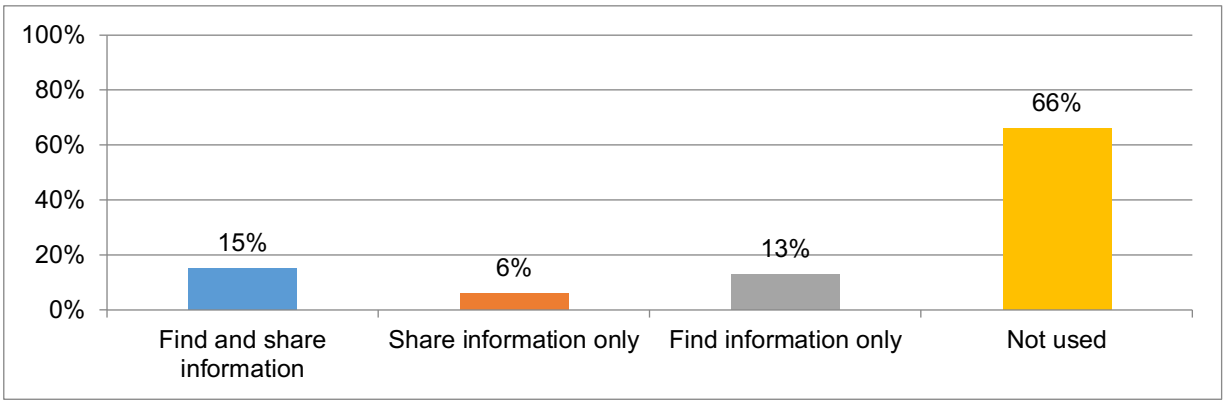


Figure 1: Use of social media (Facebook, Twitter, Instagram etc.) during an emergency (N=2000)

The survey indicated noticeable differences in the characteristics of those who have/would and have/would not used/use social media during an emergency, relative to their age, gender and social grade. In particular, respondents most likely to use it were young people, women and those in social grades ABC1. Figure 2 presents the levels of social media use in emergencies by age of participants, categorised into seven age bands. It shows that those in the youngest age band are most likely to have used it (χ^2 (6, N=1999) = 254.56, p <.001, Cramer's V =.36), although the levels of use are quite similar for those aged 25-34 and 35-44. As Figure 2 shows, there is a noticeable drop in use for those aged 45 or above – suggesting a 'digital divide' between younger and older citizens in the UK.

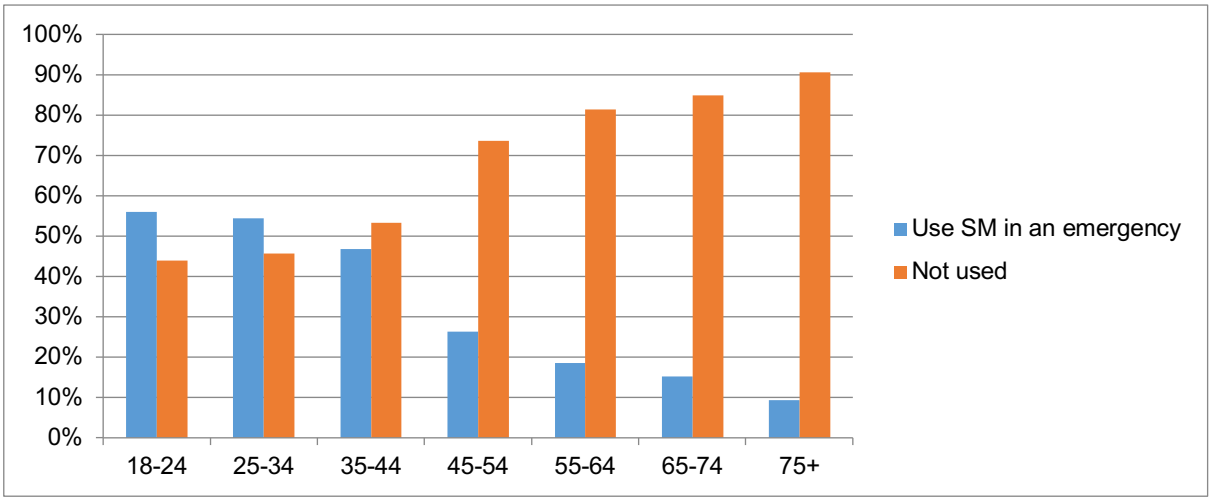


Figure 2: Use of social media in an emergency by age (N=2000)

Analysis of the data also showed that those in the youngest age group are more likely to have used social media to look for information, while those in the 25-34 age group are more likely to have used it to share information.

Age group	Use SM to look for info only	Use SM to share info	Total use
18-24	40%	16%	56%
25-34	19%	36%	54%

Table 2: Ways of using social media in emergencies by age group (N=575)

Women are also significantly more likely to have used social media in an emergency (37%) than men (31%) (χ^2 (1, N=1999) = 7.52, p <.01, Cramer's V =.061). In particular, women are more likely to use social media to share information in an emergency (23%) than men (18%) (χ^2 (2, N=1999) = 8.01 p <.05, Cramer's V =.063), while similar proportions have used it to look for information (14% of women and 13% of men, respectively). Similarly, 38% of those in the social grades ABC1 have used social media in an emergency, compared with 29% of those in

social grades C2DE (χ^2 (1, N=2000) = 18.65, p <.001, Cramer's V =.097).

While a third of respondents in the UK (34%) has used social media in an emergency, two-thirds (66%) have not done so. Asking for reasons behind not using social media in emergencies, responses (see Figure 3) suggest that citizens are mostly concerned about the trustworthiness of information on social media, that information shared on social media is not reliable (60%) and that there are many false rumours on social media (64%). These concerns were reflected in many responses to the open-ended question:

> *'I have never used social media in any emergency and would be hesitant in doing so as you could have anyone turning up and taking advantage of the situation.'*

> *'I wouldn't use social media in an emergency - far too unreliable and prone to rumour'*

Furthermore, people have technical concerns. More than half (62%) state that they are concerned about mobile phones and social media not working properly in a serious emergency and that this would (definitely) put them off using social media. Lack of confidence in using social media was only a reason for around a third (28%) of citizens.

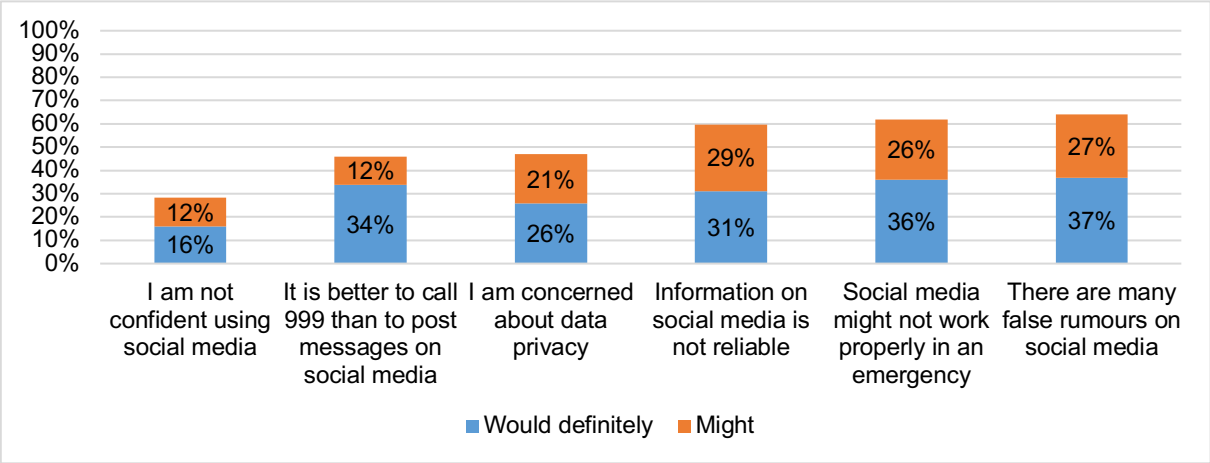


Figure 3: Reasons for not using social media during an emergency (N=2000)

In contrast, several respondents indicated several factors that would make them more likely to use social media in the future to look for or share information. Among these are information accuracy and data security as well as having assured that emergency services are actually known to look for and act on any information shared.

> *'I have never used social media in an emergency. I would need to be reassured about its reliability and that it was monitored.'*

> *'I suppose I might be likely to use it if I found that the emergency services WANTED to be contacted that way and would respond quickly'*

The 432 citizens who have already used social media to share information during an emergency were most likely to have done so to share weather conditions or warnings (43%) and road or traffic conditions (42%). A further 31% have shared their own feelings or emotions about the event (see Figure 4). However, some significant differences were revealed depending once again on gender, age and social class of citizens. The most noticeable of these were that women were significantly more likely to have shared their feelings or emotions via social media (35%) than men (25%; χ^2 (1, N=412) = 4.15, p <.05, Cramer's V =.10), while men were more likely to have shared advice on what to do to stay safe than women (23% versus 15%; χ^2 (1, N=412) = 3.89, p <.05, Cramer's V =.097). Regarding age, 18- to 34-year-olds were more likely to share eyewitness photos than citizens in older age groups (13%; χ^2 (2, N=411) = 7.38, p <.05, Cramer's V =.13). In contrast, those aged 55 or older were more likely to have shared weather conditions or warnings (59%) and road or traffic conditions (58%) than younger citizens (χ^2 (2, N=412) = 10.36, p <.01, Cramer's V =.16 and χ^2 (2, N=413) = 12.42, p <.01, Cramer's V =.17, respectively).

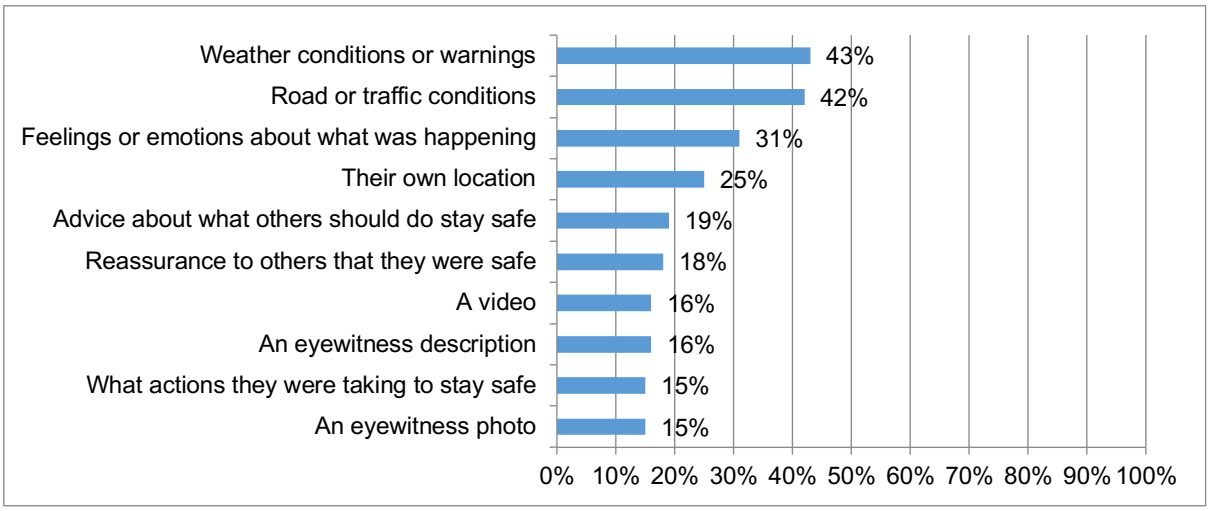


Figure 4: Types of information shared during an emergency (N=432)

Considering that a respectable proportion of respondents (21%) said to have shared information via social media and our research interest of deriving useful practical insights with respect to potentially influencing factors, we asked participants what online responses they expect from emergency services. Figure 5 shows that the majority of UK participants do not expect emergency services to respond to messages posted to them on social media during an emergency or to monitor social media. Thus, only around a third (30%) of citizens agreed or strongly agreed with the statement that they would expect to get a response to such a message within an hour. The main reason for this appears to be that more than 60% of citizens think that emergency services are too busy during an emergency to monitor social media. Indeed, medium correlations were found between thinking that emergency services are too busy and expecting emergency services to monitor social media (r_τ = -.235, p<.001) and expecting emergency services to respond within an hour (r_τ = -.246, p<.001), respectively.

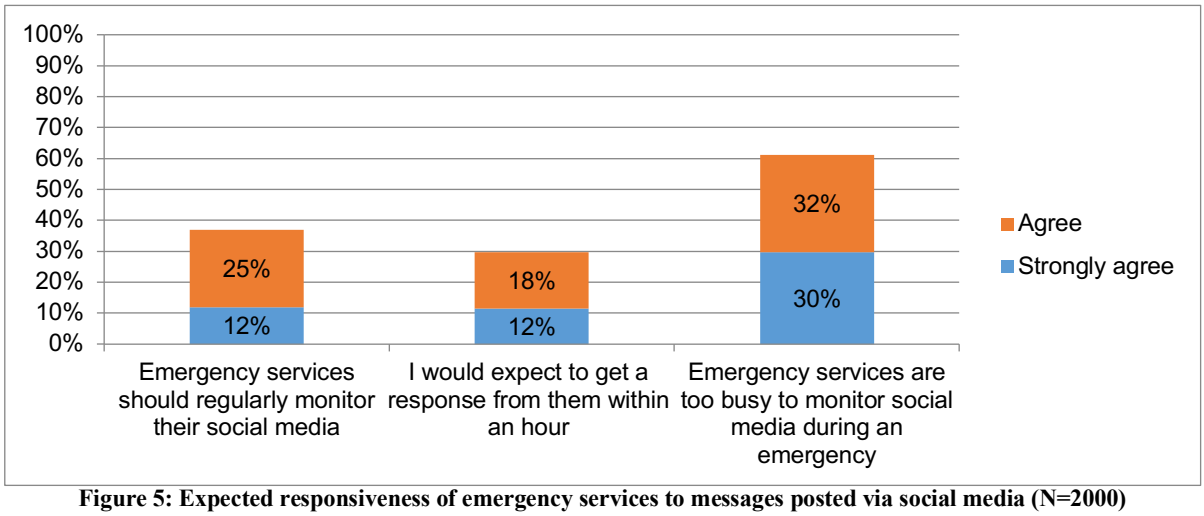


Figure 5: Expected responsiveness of emergency services to messages posted via social media (N=2000)

Despite this overall low expectation of emergency services to monitor their social media accounts and to respond to messages sent via social media, there are subgroups of citizens with higher expectations. Younger people (r_τ=.152, p<.001) and people using smartphones in their daily life (U = 307901.5, p<.001) tend to have higher expectations. Thus, for example, almost half of those aged 18-34 (48%) think that emergency services should regularly monitor their social media, compared with only 27% of those aged 55 or older and 38% of those aged 35-54. Similarly, 41% of smartphone users agreed with this statement, compared with 22% of those at the time of conducting the survey not using a smartphone.

4.3 Use of Emergency Apps

Instead of using common social media platforms, specific smartphone apps are available that could help in a disaster or emergency. Currently, such apps are not widely used in the UK. Indeed, only 7% of survey participants reported to have downloaded such an emergency app. Even when excluding those 376 participants who currently do not use a smartphone, the proportion increases only slightly to 8%. Thus, this group is likely to represent a

unique group of citizens with a particular interest in emergency response or in smartphone applications. When looking at the characteristics of this group, significant relationships were found between having downloaded an emergency app and gender, age, social grade as well as Twitter use. Firstly, 65% of those who have downloaded an emergency app were male (χ^2 (1, N=1913) = 15.15, p <.001, Cramer's V =.089) and 59% were between 25 and 34 years old (χ^2 (6, N=1911) = 116.54, p <.001, Cramer's V =.247) while 23% of the survey sample falls in this age bracket. Secondly, 80% belonged to the social grade ABC1, with only 54% of the survey sample falling in this social grade (χ^2 (1, N=1913) = 38.92, p <.001, Cramer's V =.14). Lastly, 28% of this group of respondents use Twitter hourly while there are only 4% hourly Twitter users in the sample overall (χ^2 (4, N=1913) = 261.46, p <.001, Cramer's V =.37).

Of all citizens that had downloaded an app (n=135), the most downloaded app was a weather app (44%), followed by a first-aid app (42%). A warning or alert app was downloaded by 36% and an emergency call app was only downloaded by 28%. Ten respondents indicated that they had downloaded another app that did not fall into these four broad categories including a power cut notification and a missing child alert, thus, exemplifying the potential diversity of emergency applications use. Although the vast majority of citizens (93%) have not yet downloaded an emergency app, a large proportion of respondents indicated that they were likely to use apps in the future for various reasons. It shows that citizens are generally most likely to use apps to receive information during emergencies rather than to share information (Figure 6). Around 40% thought it was at least quite likely they would use an app to find out information about an emergency while only 21% thought they would use it to contact an emergency service instead of making a 999 call. Perhaps unsurprisingly, those who had downloaded an app in the past were significantly more likely to think that it was very likely they would use an app for all of these purposes in future (U=68535.0, p<.001; U=61724.0, p<.001; U=70002.0, p<.001; U=67244.0, p<.001; U=67244.0, p<.001; U=62576.0, p<.001, respectively).

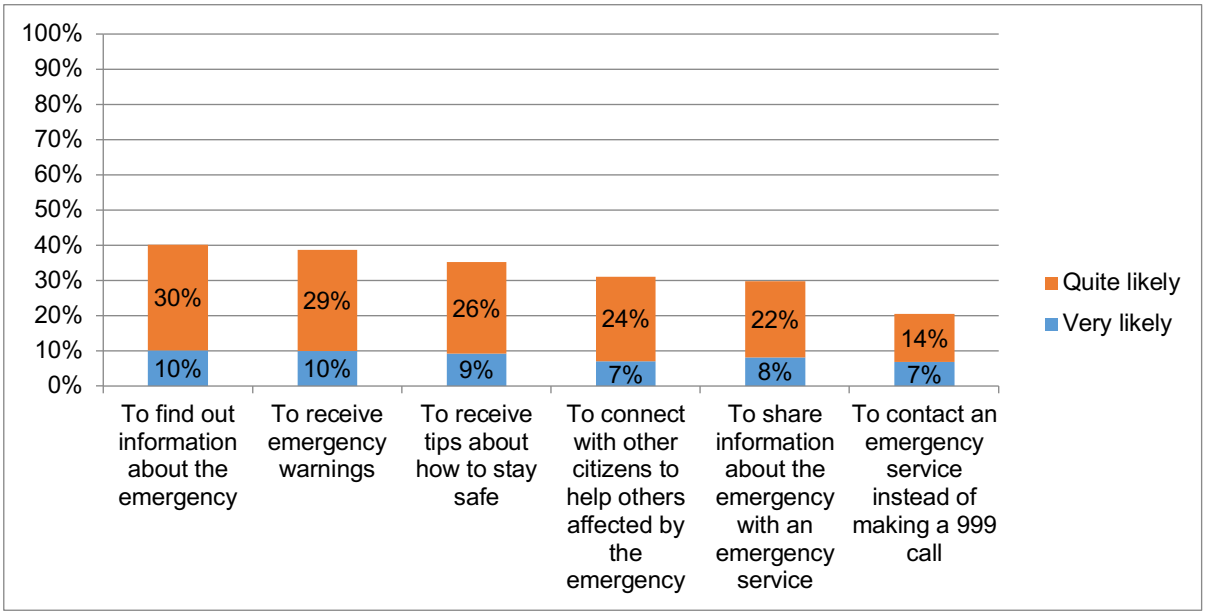


Figure 6: Likelihood of using an app in future for different purposes (N=2000)

The general trend that citizens would use such apps to receive information but not so much to share information was also found within the open question responses. For example:

> *'I would use it for additional advice/guidance but never as an alternative method to contact an emergency service.'*

Respondents further provided suggestions of additional emergency apps that they would use if they were available. Examples include: A 'check in' app which sends out text messages to let friends and family know the person is fine, a real-time time connection with emergency authorities, an app for emergencies at sea or in the mountains to locate the person, an app providing status updates.

5 DISCUSSION AND CONCLUSION

The use of social media in the UK is widespread and growing. Services such as Facebook and Twitter are still used by considerable proportions of citizens among the older generations, even though older people are significantly less likely to use them. The findings of the survey with over half (58%) of those aged 75 or above using Facebook may be surprising to some who believe that social media is predominantly used by adolescents.

Furthermore, research elaborated on potentials of new technologies for safety-critical work or, more specifically, emergency response (Norros et al., 2011). Compared with the general levels of social media usage, much lower proportions of citizens have used social media in an emergency to look for or share information. This could reflect a reluctance to do so given the perceived dangers highlighted in this survey of false rumours circulating on social media during recent crises. Yet, at the same time, it could also reflect a lack of perceived need. In particular, some people may still rely on traditional media or online news sites to provide them with information in such instances, while others may not have been in a situation where they have needed to do so.

Context, i.e. time and place, may influence social media usage as well. Thus, it is worth considering that the recent terrorist attacks carried out in the UK in 2017, including the Westminster attack on 22nd March and the Manchester bombing on 22nd May, which happened after the survey was conducted, may have increased people's use of social media in the UK during emergencies. Indeed, as reports following these attacks showed, social media was used extensively by emergency services and citizens during these events.

At present, only a relatively low proportion, around a third, of citizens in the UK expect emergency services to monitor social media and to respond to messages posted on social media. At the same time, the expectation is much greater among younger citizens and those using social media actively. This suggests that, in the coming years, more and more citizens will expect emergency services to monitor and respond to such messages. If emergency services monitor, respond to messages on social media and citizens perceive this shift in crisis communication, more and more people may start using it as a form of sharing and looking for information in cases of emergency. However, this raises some potential issues. First, as the survey has shown, social media is used the least by older, socio-economically disadvantaged citizens. This could mean that in an emergency, such as a flood or large-scale fire, emergency services are not alerted to the needs of those not using social media. Then, we could envisage a scenario in which emergency services commit increased resources to support citizens in areas with higher proportions of young and affluent social media users to the detriment of those living in areas with a poorer and older age profile. Habitual use of social media is reflected by the younger generation of 'digital natives', most open to share eyewitness pictures and most strongly expecting other entities (like emergency services) to integrate social media into their working procedures.

If organisations take this interpretation into account, social media usage might increase during emergency events. The risk of such increased use of social media during crises is that emergency services could be swamped by the information published form the civilians. Already today, emergencies are accompanied by enormous amounts of social media messages. The Brussels bombing in 2016 (McMahon et al., 2016), for example, prompted a large volume of social media traffic in the hours and days following the events, with over 2 million messages posted on Twitter. Other research has shown that during major events such as terrorist attacks, emergency services are often overwhelmed with information – including calls to emergency helplines or 999 calls – which means it could limit their ability to access or identify additional data from social media (Plotnick et al., 2015). At present, there are some social media analytics tools like AIDR or Dataminr used for event detection (Imran et al., 2014; Miller, 2017). Yet, further effort is necessary to be able to compress streams of data into manageable chunks of information.

By testing for correlations between extraordinary social media behaviour in times of crises and ordinary use, our study sheds light on specific usage patterns regarding certain social media platforms. Ensuring successful crisis communication requires emergency services to monitor and respond on various platforms simultaneously to not discriminate against socially potentially more disadvantaged individuals. At the same time, multimodal communication channels among authorities responsible for social media content, providers of news websites or of TV or radio news could prove to be helpful in spreading information to non-users of smartphones or online social media. Furthermore, our study highlighted differences in the behaviour of men and women in relation to social meda. Here, UK participants' statements reflect rather conventional gender roles with advising male respondents (Janković et al., 2017), indicating the necessity of sensitive communication.

This study has strengthened findings from previous qualitative and quantitative studies of the use and impact of social media during emergencies. In particular, it has highlighted the extent to which the use of social media is widespread among citizens in the UK and that they are increasingly using it to look for and share information during emergencies. There is also a growing trend towards sharing information, photos and videos with others and directly with emergency services – and as the latter become more responsive, this diversification of use is likely to grow. Thus, it can be said that civilians show a growing interest of using social media in any kind of

emergency, while requiring assurance by emergency services.

However, further qualitative and quantitative research is needed to explore the extent to which specific events of emergencies like recent terrorist attacks in the UK and other parts of Europe have changed citizens' attitudes towards using social media or settings in which they would use social media. This includes that there is also a need to further examine ways in which emergency services can deal with additional data in crisis situations and what tools are best suited to help them to do so.

ACKNOWLEDGEMENTS

The research project EmerGent' was funded by a grant of the European Union (FP7 No. 608352). This work was also supported by the German Federal Ministry for Education and Research (BMBF) in the project KontiKat (13N14351) as well as by the Hessen State Ministry for Higher Education, Research and the Arts (HMWK) within CRISP.

6 REFERENCES

American Red Cross. (2012). More Americans Using Mobile Apps in Emergencies. Retrieved January 15, 2019, from https://www.prnewswire.com/news-releases/more-americans-using-mobile-apps-in-emergencies-168144726.html

Barker, V. (2009). Older Adolescents' Motivations for Social Network Site Use: The Influence of Gender, Group Identity, and Collective Self-Esteem. *CyberPsychology & Behavior*, *12*(2), 209–213. https://doi.org/10.1089/cpb.2008.0228

Beynon-Davies, P. (1999). Human error and information systems failure: the case of the London ambulance service computer-aided dispatch system project. *Interacting with Computers*, *11*, 699–720. https://doi.org/10.1016/S0953-5438(98)00050-2

Canadian Red Cross. (2012). Social Media during Emergencies. Retrieved January 15, 2019, from https://www.redcross.ca/crc/documents/Social-Media-in-Emergencies-Survey-Oct-2012-English.pdf

Carroll, J. M., Rosson, M. B., Convertino, G., & Ganoe, C. H. (2006). Awareness and teamwork in computer-supported collaborations. *Interacting with Computers*, *18*(1 SPEC. ISS.), 21–46. https://doi.org/10.1016/j.intcom.2005.05.005

Chen, R., Sharman, R., Rao, H. R., & Upadhyaya, S. J. (2008). Coordination in Emergency Response Management. *Communications of the ACM*, *51*(5), 66–73. https://doi.org/10.1145/1342327.1342340

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112(1)*, 155. https://doi.org/10.1037/0033-2909.112.1.155

Correa, T., Hinsley, A. W., & de Zúñiga, H. G. (2010). Who interacts on the Web?: The intersection of users' personality and social media use. *Computers in Human Behavior*, *26*(2), 247–253. https://doi.org/10.1016/j.chb.2009.09.003

Dahl, Y., Farshchian, B., Vilarinho, T., Helbostad, J. L., Nawaz, A., Nygård, A. J., & Wik, P. B. (2016). Stakeholder attitudes toward and values embedded in a sensor-enhanced personal emergency response system. *Interacting with Computers*, *28*(5), 598–611. https://doi.org/10.1093/iwc/iwv036

Dobson, J. (2016). Measuring social class. Retrieved January 15, 2019, from https://humanrights.brightblue.org.uk/blog-1/2016/5/6/measuring-social-class

Flizikowski, A., Hołubowicz, W., Stachowicz, A., Hokkanen, L., & Delavallade, T. (2014). Social Media in Crisis Management – the iSAR + Project Survey. In S. R. Hiltz, M. S. Pfaff, L. Plotnick, & P. C. Shih (Eds.), *Proceedings of the 11th International Conference on Information Systems for Crisis Response and Management (ISCRAM)* (pp. 707–711). Brussels, Belgium: ISCRAM.

Government, U. (2018). Guidance: Emergency planning and preparedness: exercises and training. Retrieved November 29, 2018, from https://www.gov.uk/guidance/emergency-planning-and-preparedness-exercises-and-training

Gray, B., Weal, M. J., & Martin, D. (2017). Social Media during a Sustained Period of Crisis: The Case of the UK Storms. *14th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2017)*. Albi, France. https://doi.org/10.1063/1.1365077

Gunawan, L. T., Alers, H., Brinkman, W. P., & Neerincx, M. A. (2011). Distributed collaborative situation-map

making for disaster response. *Interacting with Computers*, *23*(4), 308–316. https://doi.org/10.1016/j.intcom.2011.04.003

Haddow, G. D., Bullock, J. A., & Coppola, D. P. (2002). *Introduction to Emergency Management*. (P. Chester, Ed.), *Public Administration Review* (3rd ed., Vol. 45). Burlington: Elsevier.

Hendela, A., Turoff, M., Hiltz, S., & Fjermestad, J. (2017). A Risk Scenario for Small Businesses in Hurricane Sandy Type Disasters. In *Proceedings of the 50th Hawaii International Conference on System Sciences* (pp. 257–266). Waikoloa. https://doi.org/10.24251/HICSS.2017.031

Hill, B. (2010). Diagnosing co-ordination problems in the emergency management response to disasters. *Interacting with Computers*, *22*(1), 43–55. https://doi.org/10.1016/j.intcom.2009.11.003

Hiltz, S. R., & Plotnick, L. (2013). Dealing with Information Overload When Using Social Media for Emergency Management: Emerging Solutions. In T. Comes, F. Fiedrich, S. Fortier, J. Geldermann, & T. Müller (Eds.), *Proceedings of the 10th International Conference on Information Systems for Crisis Response and Management (ISCRAM)* (pp. 823–827). Brussels, Belgium: ISCRAM.

Imran, M., Castillo, C., Lucas, J., Meier, P., & Vieweg, S. (2014). AIDR: Artificial Intelligence for Disaster Response. In *Proceedings of the Companion Publication of the 23rd International Conference on World Wide Web Companion* (pp. 159–162). Republic and Canton of Geneva, Switzerland: International World Wide Web Conferences Steering Committee. https://doi.org/https://doi.org/10.1145/2567948.2577034

International Association of Chiefs of Police. (2015). 2015 Social Media Survey Results. Retrieved January 15, 2019, from http://www.iacpsocialmedia.org/wp-content/uploads/2017/01/FULL-2015-Social-Media-Survey-Results.compressed.pdf

Janković, B., Srdić, M., & Baćanović, V. (2017). Media, Gender and the Reporting of Emergencies: A Booklet for Journalists and Professionals Dealing with Flood Reporting. Retrieved January 15, 2019, from https://www.osce.org/mission-to-serbia/314756?download=true

Kogan, M., Anderson, J., Palen, L., Anderson, K. M., & Soden, R. (2016). Finding the Way to OSM Mapping Practices: Bounding Large Crisis Datasets for Qualitative Investigation. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16* (pp. 2783–2795). San Jose, USA. https://doi.org/10.1145/2858036.2858371

Kristensen, M., Kyng, M., & Palen, L. (2006). Participatory Design in Emergency Medical Service: Designing for Future Practice. In *Proceedings of the ACM 2006 Conference on Human Factors in Computing Systems (CHI 2006)* (pp. 161–170). New York, USA: ACM Press. https://doi.org/10.1145/1124772.1124798

Lev-On, A., & Uziel, V. (2018). Live, visual, social, and mobile: media ecology in emergencies and ordinary times. *Online Information Review*, *42*(4). https://doi.org/10.1108/OIR-04-2016-0117

Lin, L., Jung, M., McCloud, R. F., & Viswanath, K. (2014). Media Use and Communication Inequalities in a Public Health Emergency: A Case Study of 2009–2010 Pandemic Influenza a Virus Subtype H1N1. *Public Health Reports*, *129*(6_suppl4), 49–60. https://doi.org/10.1177/00333549141296S408

Lo, A. Y., & Chan, F. (2017). Preparing for flooding in England and Wales: the role of risk perception and the social context in driving individual action. *Natural Hazards*, *88*(1), 367–387. https://doi.org/10.1007/s11069-017-2870-y

McMahon, H., Browning, J., Regan, A., & Dyer, N. (2016). *Geospatial Information in Emergency Management*. Retrieved from http://ggs685.pbworks.com/w/file/fetch/107793818/Edited_FIRM.pdf

Miller, R. (2017). Dataminr announces new tool to assist first responders. Retrieved November 8, 2018, from https://techcrunch.com/2017/05/15/dataminr-announces-new-tool-to-assist-first-responders-at-techcrunch-disrupt/

National Readership Survey. (2019). Social Grade. Retrieved January 15, 2019, from http://www.nrs.co.uk/nrs-print/lifestyle-and-classification-data/social-grade/

Norros, L., Liinasuo, M., & Hutton, R. (2011). Evaluating the potential of new technological tools for safety critical work. *Interacting with Computers*, *23*(4), 299–307. https://doi.org/10.1016/j.intcom.2011.05.003

Office for National Statistics. (2017). Population and migration. Retrieved January 15, 2019, from https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration

Plotnick, L., Hiltz, S. R., Kushma, J. a, & Tapia, A. (2015). Red Tape : Attitudes and Issues Related to Use of Social Media by U . S . County- Level Emergency Managers. In *Proceedings of the Information Systems*

for Crisis Response and Management (ISCRAM) (pp. 182–192). Kristiansand, Norway: ISCRAM.

Reuter, C. (2019). *Information Technology for Peace and Security - IT-Applications and Infrastructures in Conflicts, Crises, War, and Peace*. Wiesbaden, Germany: Springer Vieweg.

Reuter, C., Backfried, G., Kaufhold, M.-A., & Spahr, F. (2018a). ISCRAM turns 15: A Trend Analysis of Social Media Papers 2004-2017. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 1–14). Rochester, New York, USA: ISCRAM.

Reuter, C., Hughes, A. L., & Kaufhold, M.-A. (2018b). Social Media in Crisis Management: An Evaluation and Analysis of Crisis Informatics Research. *International Journal on Human-Computer Interaction (IJHCI)*, *34*(4), 280–294. https://doi.org/10.1080/10447318.2018.1427832

Reuter, C., & Kaufhold, M.-A. (2018). Fifteen Years of Social Media in Emergencies: A Retrospective Review and Future Directions for Crisis Informatics. *Journal of Contingencies and Crisis Management (JCCM)*, *26*, 41–57.

Reuter, C., Kaufhold, M.-A., Spielhofer, T., & Hahne, A. S. (2017). Social Media in Emergencies: A Representative Study on Citizens' Perception in Germany. In *Proceedings of the ACM: Human Computer Interaction (PACM): Computer-Supported Cooperative Work and Social Computing* (Vol. 1, pp. 1–19). New York, USA. https://doi.org/10.1145/3134725

Reuter, C., Ludwig, T., Kaufhold, M.-A., & Spielhofer, T. (2016). Emergency Services Attitudes towards Social Media: A Quantitative and Qualitative Survey across Europe. *International Journal on Human-Computer Studies (IJHCS)*, *95*, 96–111. https://doi.org/10.1016/j.ijhcs.2016.03.005

Reuter, C., & Spielhofer, T. (2017). Towards Social Resilience: A Quantitative and Qualitative Survey on Citizens' Perception of Social Media in Emergencies in Europe. *Journal Technological Forecasting and Social Change (TFSC)*, *121*(August 2017), 168–180. https://doi.org/10.1016/j.techfore.2016.07.038

Salvati, P., Bianchi, C., Fiorucci, F., Giostrella, P., Marchesini, I., & Guzzetti, F. (2014). Perception of flood and landslide risk in Italy: a preliminary analysis. *Natural Hazards and Earth System Sciences*, *14*(9), 2589–2603. https://doi.org/10.5194/nhess-14-2589-2014

San, Y., Wardell III, C., & Thorkildsen, Z. (2013). *Social Media in the Emergency Management Field: 2012 Survey Results*. National Emergency Manaagement Association.

Sarcevic, A., & Ferraro, N. (2017). On the use of electronic documentation systems in fast-paced, time-critical medical settings. *Interacting with Computers*, *29*(2), 203–219. https://doi.org/10.1093/iwc/iww021

Shan, Y., Plotnick, L., Hiltz, S., & Yang, L. (2017). A Comparison of Emergency Management Social Media Use in the United States and England. In *Twenty-third Americas Conference on Information Systems* (pp. 1–10). Boston, USA.

Starbird, K. (2017). Examining the Alternative Media Ecosystem Through the Production of Alternative Narratives of Mass Shooting Events on Twitter. In *Proceedings of the Eleventh International Conference on Web and Social Media* (pp. 230–239). Palo Alto, CA: AAAI Press.

Stieglitz, S., Dang-Xuan, L., Bruns, A., & Neuberger, C. (2014). Social Media Analytics: An Interdisciplinary Approach and Its Implications for Information Systems. *Business and Information Systems Engineering*, *6*(2), 89–96. https://doi.org/10.1007/s12599-014-0315-7

Strauss, A. L. (1987). *Qualitative Analysis for Social Scientists*. Cambridge: Cambridge Press.

UN Office for Disaster Risk Reduction. (2016). Terminology. Retrieved January 15, 2019, from https://www.unisdr.org/we/inform/terminology

We Are Social. (2016). Digital in 2016. Retrieved November 28, 2018, from https://wearesocial.com/uk/special-reports/digital-in-2016

Whittaker, J., McLennan, B., & Handmer, J. (2015). A review of informal volunteerism in emergencies and disasters: Definition, opportunities and challenges. *International Journal of Disaster Risk Reduction*, *13*, 358–368. https://doi.org/10.1016/j.ijdrr.2015.07.010

Identifying Disaster Damage Images Using a Domain Adaptation Approach

Xukun Li
Department of Computer Science
Kansas State University
xukun@ksu.edu

Doina Caragea*
Department of Computer Science
Kansas State University
dcaragea@ksu.edu

Cornelia Caragea
Department of Computer Science
University of Illinois at Chicago
cornelia@uic.edu

Muhammad Imran
Qatar Computing Research Institute
Hamad Bin Khalifa University
mimran@hbku.edu.qa

Ferda Ofli
Qatar Computing Research Institute
Hamad Bin Khalifa University
fofli@hbku.edu.qa

ABSTRACT

Approaches for effectively filtering useful situational awareness information posted by eyewitnesses of disasters, in real time, are greatly needed. While many studies have focused on filtering textual information, the research on filtering disaster images is more limited. In particular, there are no studies on the applicability of domain adaptation to filter images from an emergent target disaster, when no labeled data is available for the target disaster. To fill in this gap, we propose to apply a domain adaptation approach, called domain adversarial neural networks (DANN), to the task of identifying images that show damage. The DANN approach has VGG-19 as its backbone, and uses the adversarial training to find a transformation that makes the source and target data indistinguishable. Experimental results on several pairs of disasters suggest that the DANN model generally gives similar or better results as compared to the VGG-19 model fine-tuned on the source labeled data.

Keywords

Image classification, disaster damage, domain adaptation, domain adversarial neural networks.

INTRODUCTION

The increased popularity of social media websites has transformed the way in which affected populations communicate with response organizations during and following major disasters. Victims of several recent hurricanes, including Hurricane Harvey, Hurricane Irma and Hurricane Florence, have turned to social media to request help and assistance, as emergency hotlines were sometimes unreachable due to the high volume of calls (Rhodan 2017; MacMillan 2017; Frej 2018). According to Rhodan (2017), a woman and two children were rescued during Hurricane Harvey after the woman posted a desperate message for help on Twitter: 'I have 2 children with me and tge [sic] water is swallowing us up. Please send help.' Similarly, an image posted on Twitter, which showed 'elderly residents sitting in greenish flood water,' raised awareness of a nursing home situation and resulted in urgent help being sent to the nursing home (Rhodan 2017).

*corresponding author

While social media can help increase situational awareness, inform rescue operations, and save lives, its value is highly unexploited by response teams, in part due to the lack of tools that can help filter actionable information from the big data posted during disasters. A recent study (Villegas et al. 2018) reported that during Hurricane Harvey, FEMA missed 46% of the critical damage information posted by affected individuals on Twitter, and thus many areas heavily impacted by the hurricane were missed from the original damage estimates provided by FEMA. Similarly, Kryvasheyeu et al. (2016) used Hurricane Sandy tweets, and Enenkel et al. (2018) used Hurricanes Harvey and Irma filtered, geo-located tweets to show that rapid early damage assessment can be facilitated by social media. Among others, the above-mentioned studies (Kryvasheyeu et al. 2016; Villegas et al. 2018; Enenkel et al. 2018) suggest that tools that can identify critical social media information in real-time are greatly needed, and should be incorporated into the operational decision-making pipelines of response organizations.

To meet these requirements, many studies have focused on the design of machine learning tools to identify relevant, informative, actionable situational awareness information in social media (Vieweg et al. 2010; Sen et al. 2015; Huang and Xiao 2015; Imran et al. 2016). More recently, deep learning approaches have also been proposed in the context of identifying information useful for disaster response on social media (Caragea et al. 2016; Nguyen, Al-Mannai, et al. 2017; Neppalli et al. 2018; Derczynski et al. 2018; Aipe et al. 2018), and have been generally shown to produce better results than the traditional supervised learning approaches. As opposed to research on classifying disaster tweets, research on classifying and retrieving useful information from disaster images is still in its early stage, although recent studies have suggested that useful social awareness information can be found in social media images (Bica et al. 2017; Lagerstrom et al. 2016; Alam, Ofli, et al. 2018b). To advance the state-of-the-art in this area, Alam, Ofli, et al. (2018) and Mouzannar et al. (2018) recently published multi-modal datasets, consisting of both tweet text and images. Furthermore, Mouzannar et al. (2018) developed a deep learning approach to identify damage images in their dataset. Related to this, Nguyen, Ofli, et al. (2017) proposed to classify disaster images according to damage severity using fine-tuned convolutional neural networks, and X. Li et al. (2018) proposed a method based on class activation mapping (CAM) to localize and quantify damage in social media images posted during disasters.

While significant contributions have been made in terms of developing traditional and deep learning models to identify useful situational awareness information in social media, most of the existing approaches are supervised learning approaches, which require labeled data to train accurate models. It is unrealistic to assume that labeled data is readily available in the early hours of a disasters, when help may be most needed. Domain adaptation or transfer learning approaches (Pan and Yang 2010), which make use of labeled data from a prior disaster (called *source*) and unlabeled data from the emergent disaster (called *target*), have been shown to lead to better results as compared to supervised classifiers learned from a prior disaster, when used for target tweet classification (H. Li et al. 2017; Mazloom et al. 2018). Domain adaptation has been used extensively for image classification using deep neural networks (Wang and Deng 2018), including social media image classification by fine-tuning a pre-trained deep neural network, such as VGG-16 or VGG-19 (Simonyan and Zisserman 2014), as in (Nguyen, Ofli, et al. 2017; X. Li et al. 2018). However, domain adaptation from a source disaster to a target disaster has not been explored in the context of classifying social media images posted during and shortly after a disaster. Thus, the goal of this study is to gain insights into the usefulness of transferring knowledge from a source disaster to a target disaster, when classifying images according to damage severity.

We propose to use an approach called Domain-Adversarial Neural Network (DANN) introduced by Ganin et al. (2016). The DANN approach is based on domain-adversarial training, which reduces the shift between the source and target domains, by making the source and target feature representations indiscriminate, while the source feature representation is discriminative for the source classification task. Experimental results on images from several source-target disaster pairs have shown that the DANN approach, which uses source labeled data and unlabeled target data, can improve the classification accuracy obtained with a deep neural network trained only from source labeled data, especially if the two disasters are of different type (e.g., a hurricane and an earthquake).

The contributions of the paper are as follows:

- We have adapted the DANN model by combining it with VGG-19 to benefit from the VGG-19 extensive training.
- We have performed extensive experiments on several pairs of disasters, and studied the ability of the adapted model to transfer information about image damage from a source disaster to a target disaster.
- We have performed visualization of the original and transformed representations of the source versus target images to gain insights into the results of the model.

The rest of this paper is organized as follows: We discuss "RELATED WORK" in the section following the "INTRODUCTION". Details of the domain adversarial neural network are presented in the "BACKGROUND AND APPROACH" section. The experimental setup and results are described in "EXPERIMENTAL SETUP" and "EXPERIMENTAL RESULTS" sections, respectively. Finally, we conclude the paper, discuss the limitations of our work, and also several ideas for future work.

RELATED WORK

Domain adaptation on image data has received much attention in recent years (Gopalan et al. 2011). In particular, approaches based on Convolutional Neural Network (CNN) have been very successful, for example, Siamese networks (Bromley et al. 1993) such as the one proposed in (Long et al. 2015). Approaches based on reconstruction have also become popular. For example, Ghifary et al. (2016) applied image reconstruction on target unlabeled data by using a CNN autoencoder. Together with the reconstruction model, a supervised model was also trained on the source labeled data. The resulting model was used to retrieve information from target data. Ganin et al. (2016) applied adversarial training to adapt data from a source domain to a target domain. The adversarial training was originally used to generate synthetic images (Goodfellow et al. 2014). In domain adaptation, the adversarial training learns a data transformation which makes the source and target data to have similar distributions. Then, the classifier trained on the transformed source data can be used on the target data.

In disaster response, domain adaptation is a desirable approach, as it enables fast reaction when a disaster occurs. Several studies have applied domain adaptation approaches on disaster related text data. For example, H. Li et al. (2017) used the iterative Self-Training (Yarowsky 1995) strategy, with Naive Bayes as a base classifier, to perform domain adaptation for identifying tweets related to a disaster. Domain adversarial training has been applied to disaster tweet classification (Alam, Joty, et al. 2018). Compared to the research on disaster tweet classification, research on disaster image classification and analysis is more limited as of now. Bica et al. (2017) performed a visual analysis of two 2015 Nepal Earthquakes, and found a positive correlation between damage severity and the number of geotagged images posted by eyewitnesses of the earthquakes. Lagerstrom et al. (2016) studied the ability of machine learning approaches to identify Twitter images posted during a bush fire emergency situation, and concluded that the fire images can be identified with high accuracy.

More recently, Alam, Ofli, et al. (2018) and Mouzannar et al. (2018) recently published text and image multi-modal datasets, which have the potential to advance the state-of-the-art in disaster image analysis. Furthermore, Mouzannar et al. (2018) developed a deep learning approach to classify images based on damage. Similarly, Nguyen, Ofli, et al. (2017) used an approach based on CNNs to classify disaster images according to damage severity. Given that damage is a concept quantifiable on a continuous scale, X. Li et al. (2018) used the CAM approach to localize and quantify damage in disaster images. While these studies represent important steps towards disaster images analysis in real time, they assume target labeled data is available. Domain adaptation approaches, while greatly needed, have not been studied until now.

BACKGROUND AND APPROACH

In this section, we introduce some background on image classification, and describe the approach used to perform domain adaptation from a source disaster to a target disaster. Figure 1 shows an overview of the model used, which has the VGG-19 network (Simonyan and Zisserman 2014) as its backbone, and uses the domain-adversarial training (Ganin et al. 2016) to reduce the domain shift.

Adapted VGG-19 Architecture

Convolutional neural networks (CNN) have achieved impressive results in image analysis and computer vision. Many network architectures have been proposed for image classification in recent years, including AlexNet (Krizhevsky et al. 2012), VGG-19 (Simonyan and Zisserman 2014), ResNet (He et al. 2016). ResNet and VGG-19 models have won the ImageNet competition[1], which proves that these models have good performance on image classification. We choose VGG-19 as the backbone for our model given that this network is relatively simpler than ResNet.

As can be seen in Figure 1, VGG-19 consists of 16 convolutional layers and 3 fully connected layers. A convolutional layer can be seen as a feature extractor, as it extracts image fragments (e.g., edge) that are important with respect to the classification task, while ignoring noisy fragments which do not contribute to classification. Each convolutional layer is accompanied by a non-linear ReLU activation. The 5 max pooling layers shown in the figure are used to achieve dimensionality reduction and further filter out noise. The standard VGG-19 has two fully connected layers

[1] http://image-net.org/challenges/LSVRC/

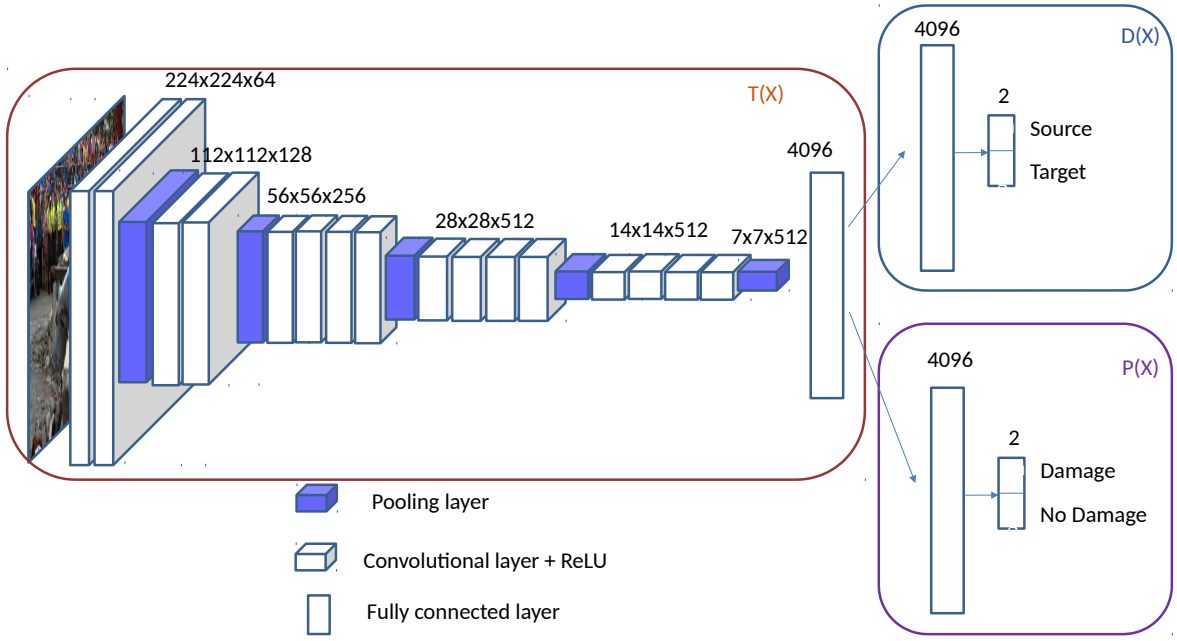


Figure 1. Overview of the Model Architecture.

with dimension 4096, and one softmax layer with dimension 1000. The softmax layer has dimension 1000 because VGG-19 was originally trained for a 1000-class object classification task. However, we aim to adapt VGG-19 to classify disaster images in two classes: *damage* or *no-damage*, and thus, we have changed the dimension of the softmax layer from 1000 dimensions to 2 dimensions. The VGG-19 model includes more then 130 million parameters that need to be learned. It is unfeasible to learn all those parameters from scratch. Instead, we have used the pre-trained VGG-19 model to initialize the parameter values in our network for all, but the last fully connected layer (as that layer has a different dimension), and subsequently fine-tuned all parameters of the model based on our disaster data. Given that the pre-trained VGG-19 model is learned from millions of images, it is known to generalize well to other sets of images in terms of informative features that it extracts. Thus, we can fine-tune it to our specific classification task with a relatively small number of images.

Domain-Adversarial Neural Networks

Domain Adaptation is a machine learning setting, where data from a source domain, X_s, is used to predict a target domain, X_t, under the assumption that the source and target domains have different distributions (a.k.a., domain shift), but share some similar patterns. In unsupervised domain adaptation, the labels of the source domain data, denoted as y_s, are available, while the labels of the target domain data, y_t, are not available. The task is to learn a classifier for the target data, using the labeled source data and the unlabeled target data. A standard approach to domain adaptation is to transform the source and target data representation (a.k.a., feature adaptation), so that the source and target distributions become indistinguishable (Pan and Yang 2010). More precisely, one needs to identify a transfer function, $T(X)$, to transform the original source, X_s, and target, X_t, domain data into $T(X_s)$ and $T(X_t)$ data which have similar distributions. Intuitively, a classifier learned on $T(X_s)$ with labels y_s should presumably have a good predictive performance on $T(X_t)$. Thus, the domain adaptation problem is reduced to finding the transfer function $T(X)$. Inspired by the generative adversarial network (GAN) proposed by Goodfellow et al. (2014), Ganin et al. (2016) designed a Domain-Adversarial Neural Network (DANN), which includes a component that explicitly aims to reduce the shift between a source and a target.

We have adapted the DANN model proposed by Ganin et al. (2016) by combining its adversarial training with the VGG-19 network, to take advantage of the extensive training of VGG-19. The architecture of the adapted DANN network, is shown in Figure 1. As can be seen in Figure 1, our model includes three components: 1) a transfer network, denoted by T, which enables the transfer of information from the source to the target, by reducing the shift between the two domains (in our case, between the two disasters); 2) a domain discriminative network, denoted by D, which identifies if an input image is from the source or from the target domain; 3) a prediction network, denoted by P, which is used to predict if an image is in the *damage* category or in the *no-damage* category. The input for the

transfer network, T, consists of images from either source or target domain. After applying the transformation T to the source or target images, the transformed images are classified as *source* or *target* by the discriminative network D, and classified as *damage* or *no-damage* by the predictor network P. Informally, the idea of the adversarial training is to train a good domain discriminant to separate the source and target domains, and at the same time, train a transfer network to make the two domain look so similar, that even a good discriminant network can not separate them. The predictor network, P, is trained on the transformed source data and then used to classify the transformed target data.

As can be seen in Figure 1, the transfer network, $T(X)$, consists of the first 16 convolutional/pooling layers of VGG-19, together with the first fully connected layer in VGG-19. The domain discriminative network, $D(X)$, and prediction network, $P(X)$, have similar architectures, which are equivalent to the last two fully connected layers of VGG-19. Specifically, $D(X)$ has one fully connected layer with dimension 4096, and one fully connected softmax layer with two dimensions, corresponding to the source (S) and the target (T) domains, respectively. Similarly, $P(X)$ has one fully connected layer with dimension 4096, and one fully connected softmax layer with two dimensions, corresponding to *damage* and *no-damage* categories, respectively.

DANN Model Training

The DANN is trained by minimizing the total loss of the model shown in Figure 1. To define the total loss function, we first define the following cross-entropy loss functions, corresponding to the three sub-networks in our model:

$\mathcal{L}_{prediction} = \min_{P} \mathcal{L}(y_s, P(T(x)))$, where y_s is the true class label of the transform instance x.

$\mathcal{L}_{domain} = \min_{D} \mathcal{L}(TDL, D(T(x)))$, where TDL is the true domain label, i.e., S for *source*, and T for *target*.

$\mathcal{L}_{transfer} = \min_{T} \mathcal{L}(FDL, D(T(x)))$, where FDL is a fake domain label, i.e., S for *target*, and T for *source*.

The total loss is defined as follows: $\mathcal{L}_{total} = \mathcal{L}_{domain} + \mathcal{L}_{transfer} + \mathcal{L}_{prediction}$

Let θ_D denote all the parameters in $D(X)$, θ_T denote all the parameters in $T(X)$, and θ_P denote all the parameters in $P(X)$. At each training step (a pass through the source data), we first compute each loss, $\mathcal{L}_{domain}$, $\mathcal{L}_{transfer}$, and $\mathcal{L}_{prediction}$, and update the parameters accordingly. However, we notice that the discriminant loss function always 'defeats' the transfer loss function. To account for this, we compute the transfer loss function two times in each step, as suggested in (Bang and Shim 2018). Then, the transfer and domain losses become almost equal, which means the transfer function reduced the difference between the two domains to an extent that the discriminant function can not separate the domains. The update rules are shown below:

$$\theta_D \longleftarrow \theta_D - \mu \frac{\partial \mathcal{L}_{domain}}{\partial \theta_D} \quad (1)$$

$$\theta_T \longleftarrow \theta_T - \mu \frac{\partial \mathcal{L}_{transfer}}{\partial \theta_T} \quad (2)$$

$$\theta_T \longleftarrow \theta_T - \mu \frac{\partial \mathcal{L}_{prediction}}{\partial \theta_T} \quad (3)$$

$$\theta_P \longleftarrow \theta_P - \mu \frac{\partial \mathcal{L}_{prediction}}{\partial \theta_P} \quad (4)$$

where μ is the learning rate. We use the stochastic gradient descent (SGD) to optimize the parameters. The pseudocode for training the DANN network using SGD is shown in Algorithm 1. Parameter updates are performed for each batch sampled from source. Corresponding to a batch from source of size m (line 5 in the algorithm), which is used to train the prediction network, the algorithm also creates a batch that has half (i.e., $m/2$) source instances and half target instances (line 6 in the algorithm). The source/target batch is used to train the transfer and domain networks.

EXPERIMENTAL SETUP

In this section, we present the experimental setup, including the dataset used, cross-validation setup, baselines, and implementation details. The experiments conducted in this study were designed to answer the following research questions: (1) How does the DANN model work for adaptation between disasters of the same type (e.g., two earthquakes) versus adaptation between disasters of different types (e.g., an earthquake and a hurricane)? (2) Does the source-target feature adaptation through DANN give better results as compared to the direct source adaptation from VGG-19? (3) How do the results of the DANN model compare to the results of a VGG-19 network adapted based on data from the target domain itself?

Algorithm 1 DANN Training Using SGD

Input: Datasets $S = \{(x_i^s, y_i^s)\}_{i=1}^{n_s}$ (where n_s represents the number of instances in the source S) and $T = \{x_i^t\}_{i=1}^{n_t}$ (where n_t represents the number of instances in the target T)
Output: $\theta_T, \theta_P, \theta_D$

$\theta_T \leftarrow$ pre-trained VGG-19 weights
$\theta_P, \theta_D \leftarrow$ random initial weights
$Step\ k = 0$
for k from 1 to $steps$ **do**
  for each source batch $\{(x_i^s, y_i^s)\}_{i=1}^{m}$ **do**
    Sample source/target batch $(x_j^s, x_j^t)_{j=1}^{m/2}$
    $TDL_j = 1$ if $x_j \in$ source, 0 otherwise
    $FDL_j = 0$ if $x_j \in$ source, 1 otherwise
    Compute the loss $\mathcal{L}_{domain}$
    Update θ_D using Equation (1)
    Compute the loss $\mathcal{L}_{transfer}$
    Update θ_T using Equation (2)
    Compute the loss $\mathcal{L}_{transfer}$
    Update θ_T using Equation (2)
    Compute the loss $\mathcal{L}_{prediction}$
    Update θ_T and θ_P using Equations (3) and (4)

Table 1. Disaster class distribution, together with the total number of labeled images in each disaster.

Class	Nepal Earthquake	Ecuador Earthquake	Ruby Typhoon	Matthew Hurricane
Damage	11,183	933	433	204
No-damage	7,919	791	400	127
Total	19,102	1,724	833	331

Dataset

We used the disaster image dataset published by Nguyen, Alam, et al. (2017) in our experiments. The dataset contains images from four disasters, specifically Nepal Earthquake, Ecuador Earthquake, Ruby Typhoon, and Matthew Hurricane. In the original dataset, there are three damage classes: *severe*, *mild*, and *none*. However, Nguyen, Alam, et al. (2017) suggested that the task of discriminating between *mild* and *severe* damage is very subjective, and there is significant overlap in the dataset between the two classes. Therefore, we combine the classes *severe* and *mild* into one class called *damage*. Our goal is to identify images that include damage and separate them from images that do not show any damage. Table 1 shows the total number of images in each disaster, and also the class distribution for each disaster.

Setup

Given the four disasters in our dataset, we experiment with all possible source/target pairs. Thus, some source/target pairs consist of disasters of the same type (e.g., two earthquakes), while other pairs consist of disasters of different types (e.g., an earthquake and a hurricane). Furthermore, some pairs have smaller amounts of source data, while others have larger amounts of source data. Similarly, some pairs have a smaller amount of target unlabeled data, while other pairs have a larger amount of target unlabeled data. This variety of pairs makes it possible to answer the research questions we have raised.

For each source/target experiment, we randomly split the target data into target unlabeled (80%) and target test (20%). Each DANN model was trained on all source data and the target unlabeled data, and subsequently tested on the test dataset. The results are evaluated using four standard metrics, specifically, accuracy, precision, recall and F1-measure. For cross-validation purposes, we created three different random splits for each source/target pair. The metrics reported represent averages over the three random splits (together with the standard deviation).

Baselines

We compared the DANN model against two baselines: 1) a model that uses only the labeled source data to adapt the pre-trained VGG-19 – this model can generally be seen as a lower bound for domain adaptation; 2) a model that uses the target data as labeled data to adapt the pre-trained VGG-19 – this model can generally be seen as an upper bound for domain adaptation.

Implementation Details

We used TensorFlow's MomentumOptimizer procedure to train the model using the mini-batch stochastic gradient descent on a K80 graphics card. Based on our preliminary experimentation, we set the learning rate to 0.001, and the batch size to 64 images. Furthermore, we used the dropout technique with a rate of 0.5 to prevent overfitting. The code for the VGG-19 model was adapted from https://github.com/machrisaa/tensorflow-vgg.

EXPERIMENTAL RESULTS

The results of the experiments are shown in Table 2 for the DANN model, which was trained on source labeled and target unlabeled data (denoted as DANN-SL-TU), and for the two baselines, VGG-19-SL (VGG-19 adapted using source labeled data), and VGG-19-TL (VGG-19 adapted using target labeled data). The DANN model and the baselines are tested on the same target test data. Each experiment was repeated three times with different target unlabeled/test splits, and the results averaged over the three runs.

Discussion of the Results

To answer our first research question, *How does the DANN model work for adaptation between disasters of the same type versus adaptation between disasters of different types?*, we compare the results of DANN-SL-TU with the results of VGG-19-SL for pairs of similar and different disasters. We consider Matthew Hurricane and Ruby Typhoon to be disasters of the same type, and the same for Ecuador Earthquake and Nepal Earthquake. Disaster pairs consisting of a hurricane/typhoon and an earthquake are considered to be different. As can be seen from Table 2, the results of DANN-SL-TU are similar and sometimes better than the results of VGG-19-SL, for pairs of similar disasters. Furthermore, the DANN-SL-TU results are generally better than the VGG-19-SL results for different disasters. For example, when we use either Ecuador Earthquake or Nepal Earthquake as source, the results for predicting the other earthquake are similar between DANN-SL-TU and VGG-19-SL. However, if we use either disaster as source, and predict Matthew Hurricane or Ruby Typhoon, DANN-SL-TU gives significantly better results. Similarly, when Ruby Typhoon is used as source, the results obtained with DANN-SL-TU for Nepal Earthquake and Ecuador Earthquake are significantly better then the results obtained with VGG-19-SL, while the two models are similar for Matthew Hurricane.

Given the above-mentioned results, the answer to our second question, *Does the source-target feature adaptation through DANN give better results as compared to the direct source adaptation from VGG-19?*, is overall positive, as the DANN-SL-TU model gives similar or better results than VGG-19-SL. However, if we consider the size of the datasets used in our experiments, the results in Table 2 suggest that the DANN-SL-TU approach gives better results if the source labeled data and the target unlabeled data used for training are relatively large (e.g., a few thousands). Furthermore, it can be seen that DANN increased the recall for the damage class in most case, especially when the source and target disasters are of different types. Finally, when comparing DANN-SL-TU with VGG-19-TL to answer our third question, *How do the results of the DANN model compare to the results of a VGG-19 network adapted based on data from the target domain itself?*, we observe that indeed VGG-19-TL acts as an upper bound for the DANN-SL-TU model. While the gap between the two models is significant, the gap between VGG-19-TL and VGG-19-SL is also large, suggesting that the source data distribution is indeed different from the target data distribution, and better domain adaptation models have the potential to bridge the gap.

Figure 2 shows examples of images that are correctly classified or miss-classified by the DANN-SL-TU/VGG-19-SL/VGG-19-TL networks, when Ruby Typhoon is used as target disaster and Ecuador Earthquake is used as source disasters. Specifically, the top row in Figure 2 shows examples of images that are correctly classified as *damage* by DANN-SL-TU and VGG-19-TL, but miss-classified as *no-damage* by VGG-19-SL. As the VGG-19-SL network is trained to recognize earthquake damage, it can fail to recognize rain/flood/wind damage present in typhoon images. As opposed to that, the middle row in Figure 2 shows images that are miss-classified as *damage* by both DANN-SL-TU and VGG-19-TL, but correctly classified as *no-damage* by VGG-19-SL. It seems that the networks that use images from the target typhoon during training may over-learn that water-related or wind-like images are showing damage. Finally, the bottom row in Figure 2 shows images that are miss-classified by both DANN-SL-TU

Table 2. Classification results: average accuracy (Acc.), precision (Prec.), recall (Rec.) and F1-measure (F1) for the damage class (average is taken over three runs), together with the corresponding standard deviation (in parentheses), for DANN-SL-TU (which uses source labeled data and target unlabeled data), VGG-19-SL (adapted using source labeled data), and VGG-19-TL (adapted using target labeled data). Highlighted in bold font are results that are statistically different when comparing VGG-19-SL and DANN-SL-TU using a paired t-test with $p \leq 0.05$.

Source	Ecuador Earthquake											
Target	Matthew Hurricane				Nepal Earthquake				Ruby Typhoon			
	Acc.	Prec.	Rec.	F1	Acc.	Prec.	Rec.	F1	Acc.	Prec.	Rec.	F1
VGG-19-SL	0.557	0.786	0.382	0.514	0.828	0.861	0.841	0.851	0.625	0.823	0.360	0.499
	(0.023)	(0.058)	(0.014)	(0.017)	(0.006))	(0.004)	(0.012)	(0.006)	(0.023)	(0.074)	(0.048)	(0.043)
VGG-19-TL	0.821	0.823	0.902	0.859	0.897	0.911	0.916	0.912	0.864	0.872	0.896	0.872
	(0.015)	(0.026)	(0.000)	(0.011)	(0.005)	(0.019)	(0.034)	(0.005)	(0.012)	(0.029)	(0.049)	(0.011)
DANN-SL-TU	**0.687**	0.791	**0.683**	**0.726**	0.820	0.842	0.840	0.726	**0.741**	0.774	**0.728**	**0.744**
	(0.026)	(0.089)	(0.085)	(0.023)	(0.006)	(0.025)	(0.013)	(0.023)	(0.027)	(0.072)	(0.093)	(0.031)
Source	Nepal Earthquake											
Target	Matthew Hurricane				Ecuador Earthquake				Ruby Typhoon			
	Acc.	Prec.	Rec.	F1	Acc.	Prec.	Rec.	F1	Acc.	Prec.	Rec.	F1
VGG-19-SL	0.642	0.916	0.455	0.606	0.873	**0.908**	0.852	0.878	0.699	**0.890**	0.483	0.622
	(0.052)	(0.035)	(0.078)	(0.077)	(0.006)	(0.026)	(0.026)	(0.006)	(0.039)	(0.036)	(0.078)	(0.077)
VGG-19-TL	0.821	0.823	0.902	0.859	0.923	0.908	0.957	0.930	0.864	0.872	0.896	0.872
	(0.015)	(0.026)	(0.000)	(0.011)	(0.010)	(0.040)	(0.023)	(0.008)	(0.012)	(0.029)	(0.049)	(0.011)
DANN-SL-TU	**0.706**	0.860	**0.634**	**0.724**	0.871	0.860	**0.909**	0.884	**0.800**	0.808	**0.812**	0.819
	(0.023)	(0.086)	(0.088)	(0.038)	(0.023)	(0.025)	(0.038)	(0.022)	(0.042)	(0.043)	(0.065)	(0.042)
Source	Matthew Hurricane											
Target	Ecuador Earthquake				Nepal Earthquake				Ruby Typhoon			
	Acc.	Prec.	Rec.	F1	Acc.	Prec.	Rec.	F1	Acc.	Prec.	Rec.	F1
VGG-19-SL	0.747	0.744	0.813	0.777	0.760	0.788	0.808	0.797	0.683	0.650	0.851	0.736
	(0.009)	(0.013)	(0.006)	(0.005)	(0.009)	()0.008)	(0.036)	(0.014)	(0.006)	(0.011)	(0.023)	(0.002)
VGG-19-TL	0.923	0.908	0.957	0.930	0.897	0.911	0.916	0.912	0.864	0.872	0.896	0.872
	(0.010)	(0.040)	(0.023)	(0.008)	(0.005)	(0.019)	(0.034)	(0.005)	(0.012)	(0.029)	(0.049)	(0.011)
DANN-SL-TU	0.761	0.747	**0.870**	**0.802**	0.755	0.784	0.805	0.793	0.681	0.669	0.774	0.713
	(0.038)	(0.054)	(0.037)	(0.023)	(0.023)	(0.012)	(0.073)	(0.030)	(0.024)	(0.038)	(0.103)	(0.032)
Source	Ruby Typhoon											
Target	Matthew Hurricane				Nepal Earthquake				Ecuador Earthquake			
	Acc.	Prec.	Rec.	F1	Acc.	Prec.	Rec.	F1	Acc.	Prec.	Rec.	F1
VGG-19-SL	0.741	0.817	0.748	0.778	0.731	**0.849**	0.658	0.741	0.740	**0.865**	0.618	721
	(0.018)	(0.016)	(0.027)	(0.022)	(0.009)	(0.010)	(0.008)	(0.008)	(0.018)	(0.016)	(0.027)	(0.022)
VGG-19-TL	0.821	0.823	0.902	0.859	0.897	0.911	0.916	0.912	0.923	0.908	0.957	0.930
	(0.015)	(0.026)	(0.000)	(0.011)	(0.005)	(0.019)	(0.034)	(0.005)	(0.010)	(0.040)	(0.023)	(0.008)
DANN-SL-TU	0.736	0.818	0.740	0.774	**0.763**	0.813	**0.777**	**0.792**	**0.809**	0.814	**0.840**	**0.825**
	(0.017)	(0.057)	(0.051)	(0.009)	(0.021)	(0.023)	(0.083)	(0.033)	(0.032)	(0.024)	(0.080)	(0.037)

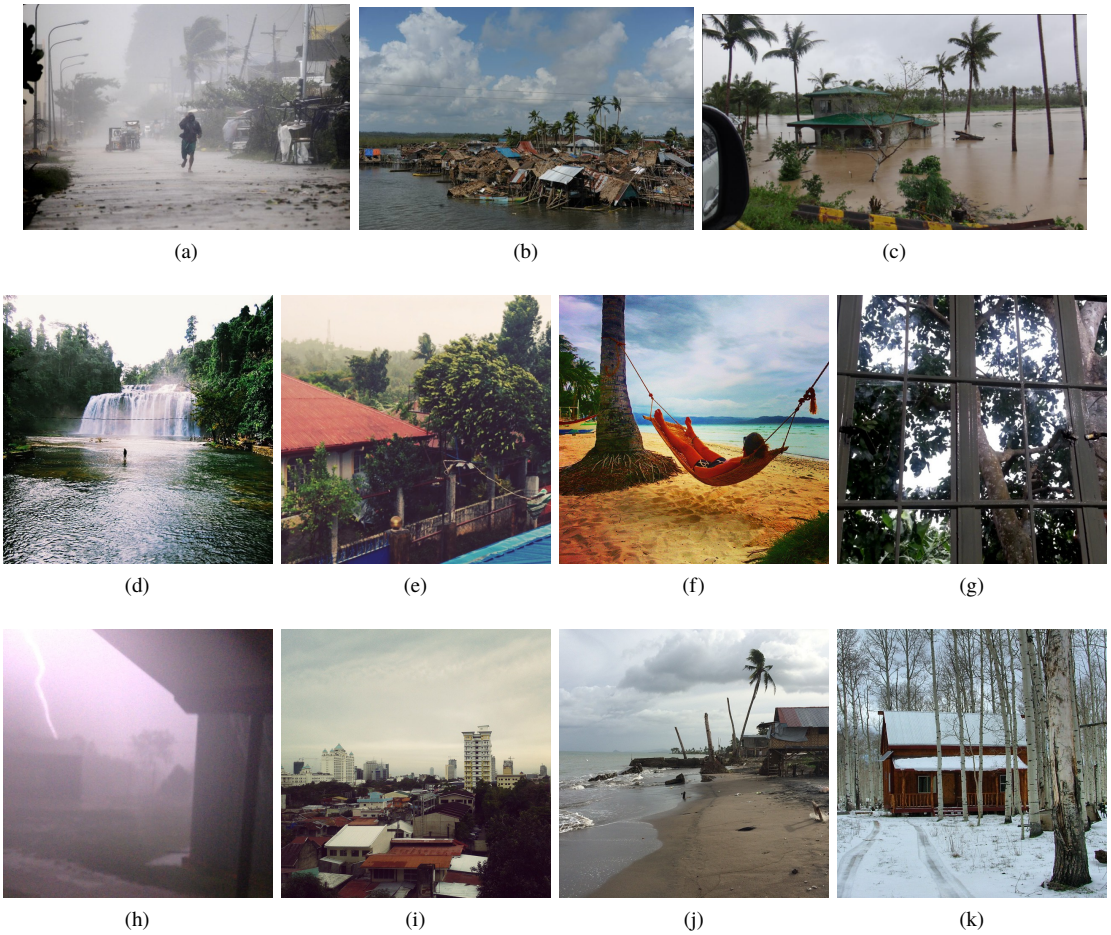


Figure 2. Examples of images that are correctly classified or miss-classified by different networks, when Ruby Typhoon is used as target disaster and Ecuador Earthquake is used as source disaster. (Top) Images that are classified correctly as *damage* by DANN-SL-TU and VGG-19-TL, and miss-classified as *no-damage* by VGG-19-SL. (Middle) Images that are miss-classified as *damage* by DANN-SL-TU and VGG-19-TL, while VGG-19-SL correctly classifies them as *no-damage*. (Bottom) The first two images on the left are miss-classified by both DANN-SL-TU and VGG-19-SL, while VGG-19-TL correctly classifies image (h) as *damage* and image (i) as *no-damage*. The last two images on the right have label *no-damage* and are miss-classified by all networks as *damage*.

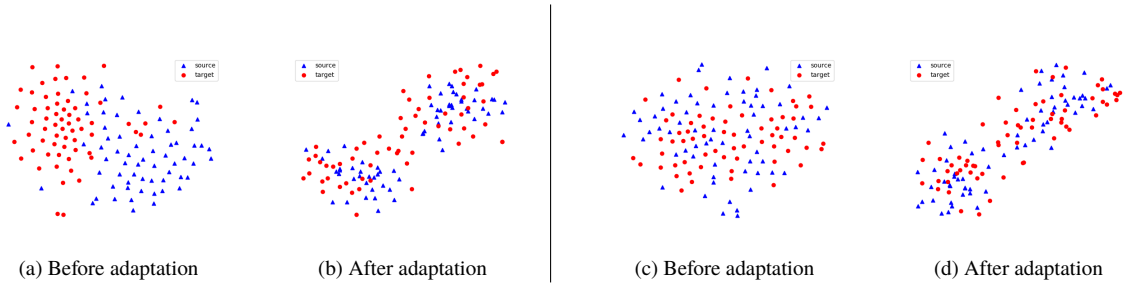
and VGG-19-SL. The first two images in the bottom row are correctly classified by VGG-19-TL as *damage* and *no-damage*, respectively, while the last two images are also miss-classified by VGG-19-TL as *damage*. Together with the quantitative evaluation in Table 2, these examples suggest that more unlabeled images from the target, and ideally more labeled images from the source, can potentially improve the results.

Estimating the Distance between Source and Target Domains before and after Adaptation

To evaluate the difficulty of the domain adaptation tasks in our study, we used the proxy $\mathcal{A}$-distance (Ben-David et al. 2007) to measure the domain shift. We expect domain adaptation to give better results than VGG-19-SL if the source and target domains are different, and similar results if the target and source domains are similar. Table 3 shows the domain pairs used in our experiments and their corresponding domain divergence in terms of the proxy $\mathcal{A}$-distance, before and after feature adaptation. To compute the proxy $\mathcal{A}$-distance, we trained a CNN model to separate the source domain X_S from the target domain X_T using unlabeled data. Then, we calculated the proxy $\mathcal{A}$-distance as $2(1 - 2\epsilon)$, where ϵ is the mis-classification error on test data. A high proxy $\mathcal{A}$-distance means that the two domains are far apart, and benefit from adaptation. A proxy $\mathcal{A}$-distance close to zero means that the two domains have essentially the same distribution. In addition to the proxy $\mathcal{A}$-distance before adaptation, we also calculated the proxy $\mathcal{A}$-distance after adaptation to understand if domains with different distributions are brought closer through adaptation. We should note that the model used to obtain the proxy $\mathcal{A}$-distance between $T(X_S)$ and $T(X_T)$ is equivalent with a two layer perceptron network, based on our model architecture. In practice, we found that sometimes the classification error may be larger than 0.5, which resulted in a negative value for the proxy

Table 3. Proxy $\mathcal{A}$-distance between different domains. In the 'After Adaptation' case, $(A \rightarrow B)$ means that the model was trained with A as source and B as target, while $(B \rightarrow A)$ means that the model was trained with B as source and A as target.

Domain A	Domain B	Before Adaptation	After Adaptation $(A \rightarrow B)$	After Adaptation $(B \rightarrow A)$
Matthew Hurricane	Ruby Typhoon	1.287	0.625	0.141
Ecuador Earthquake	Matthew Hurricane	1.633	0.125	0.141
Ecuador Earthquake	Ruby Typhoon	1.637	0.250	0.219
Nepal Earthquake	Ecuador Earthquake	1.831	0.132	0.091
Nepal Earthquake	Matthew Hurricane	1.951	0.078	0.281
Nepal Earthquake	Ruby Typhoon	1.915	0.112	0.288



(a) Before adaptation (b) After adaptation (c) Before adaptation (d) After adaptation

Figure 3. Two dimensional representation of source (blue) and target (red) using the VGG-19-SL representation of the images (before adaptation), and the DANN-SL-TU transformed representation of the images (after adaptation), for two pairs of disasters. The pair on the left consists of two dissimilar disasters, Ecuador Earthquake (source, blue) and Ruby Typhoon (target, red). The pair on the right consists of two similar disasters, Ecuador Earthquake (source, blue) and Nepal Earthquake (target, red).The two representations are reduced to 2 dimensions using the t-SNE (Van Der Maaten 2014) technique.

$\mathcal{A}$-distance. In such cases, we took the absolute value of the proxy $\mathcal{A}$-distance, as suggested in (Ben-David et al. 2007). From Table 3, we can see that the distance between Matthew Hurricane and Typhoon Ruby is the smallest among all the distances, suggesting that the distributions of the two disasters are similar. Also, considering the pairs which contain Nepal Earthquake, we can see that the smallest distance is obtained for Ecuador Earthquake. Thus, the distances in Table 3 generally are in agreement with the classification results in Table 2. It is also interesting to note that, after domain adaptation, all proxy $\mathcal{A}$-distances become smaller, which means that the distributions of $T(X_S)$ and $T(X_T)$ are more similar as compared to the original distributions of the source and target datasets.

Visual Distribution Analysis

It can be proven that $T(X_S)$ and $T(X_T)$ have similar distributions after the domain adversarial training. Here, we visualize $T(X_S)$ and $T(X_T)$ for some sample source/target pairs to visually analyze the distributions of the transformed source and target data, by comparison with the distribution of the original source and target data.

To perform this visualization, first, we randomly selected 64 images from Ruby Typhoon and 64 images from Ecuador Earthquake, two disasters with relatively high distance. Using the VGG-19 model trained on Ecuador Earthquake, we extracted the weights of the last fully connected layer in the VGG-19 model (this layer has dimension 4096). Next, we used t-SNE (Van Der Maaten 2014) to reduce the dimensionality from 4096 to 2. As a result, each image is represented by a two dimensional vector. We plotted the 128 images using the binary representation in Figure 3 (a), where we used blue triangles for images from Ecuador Earthquake and red dots for images from Ruby Typhoon. Similarly, using the DANN model trained on Ecuador Earthquake as source and Ruby Typhoon as target, we extracted the weights of the first fully connected layer, which represents the output of the transfer function $T(x)$. The graph for the 128 images (from Ecuador Earthquake and Ruby Typhoon) is shown in Figure 3 (b), where the blue triangles represent images from Ecuador Earthquake and the red dots represent images from Ruby Typhoon. As can be seen, the graph in Figure 3 (a) shows a clear boundary between the two domains, while in the graph in Figure 3 (b) the two domains are harder to separate as their distributions overlap significantly. Thus, the visualization of the reduced representations shows that after domain adaptation, the difference between source (Ecuador Earthquake) and target (Ruby Typhoon) has been indeed reduced.

In addition to performing the visualization of the transformed representations for two domains with high distance, we also performed if for two domains with relatively smaller distance. Specifically, we randomly selected 64

images from Nepal Earthquake and 64 images from Ecuador Earthquake. Following the same procedure described above, we plot two graphs in Figure 3 (c) and (d), respectively. In (c), the VGG-19 model was trained on Ecuador Earthquake and in (d), the DANN model was trained on Ecuador Earthquake as source and Nepal Earthquake as target. As can be seen in (c), the distributions of the two domains are indistinguishable even before adaptation, as the two domains have similar distributions in the first place. Thus, in this situation, DANN can not improve much the results of VGG-19, as the domains are already similar.

CONCLUSIONS AND DISCUSSION

In this paper, we studied the application of domain adaptation to identify disaster images that show damage. We adapted the DANN approach by combining it with the VGG-19 model, and thus taking advantage of the available labeled data used to train VGG-19. Experimental results suggest that the domain adaptation approach is especially useful when the source and target disasters are of different types, and thousands of labeled instances are available for the source disaster (a requirement which can be met without much effor or cost).

Given that the proposed approach does not require labeled data from the target domain, it can potentially be used to identify damage images in nearly real time. To do this, one would first use a pre-trained model that identifies images relevant to disasters and filters out non-relevant images. A model like this is already available as part of the AIDR platform (`http://aidr.qcri.org`), as described by Nguyen, Alam, et al. (2017). Subsequently, our approach can be used to identify images that show damage, by first employing the model pre-trained on source data, and gradually adapting it based on unlabeled disaster-relevant target images. The identified damage images could be used to perform fast damage assessment, which in turn can results in faster disaster response. Thus, we envision that our approach, together with relevancy-filtering models, can be incorporated in the routine operations of disaster response and management organization.

We should note that our current models were trained to distinguish between damage and no-damage images. This is a limitation imposed by the data that was available for training, which did not discriminate well between severe and mild damage classes. However, as labeled images for more specific classes of damage become available, our models can be re-trained and adapted to identify such classes. Moreover, one can further analyze images that show damage by localizing and quantifying damage on a continuous scale, as shown in X. Li et al. (2018). Such level of detail can help response teams prioritize their operations based on the severity of the damage, assuming that resources are scarce.

As part of future work, we plan to apply the DANN approach to other disaster image classification problems, for example, specific types of damage including building damage, road damage, bridge damage, human damage, etc. We also plan to study other domain adaptation approaches in the context of image analysis for disaster response. Finally, we aim to study approaches that can help identify image features indicative of damage, or even other features that might be useful for response teams.

ACKNOWLEDGEMENTS

We thank the National Science Foundation and Amazon Web Services for support from grants IIS-1741345 and IIS-1802284, which supported the research and the computation in this study. We also thank the National Science Foundation for support from the grants IIS-1526542 and CMMI-1541155, which partially supported this research. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either express or implied, of the National Science Foundation or AWS. Finally, we thank our anonymous reviewers for their constructive comments.

REFERENCES

Aipe, A., Mukuntha, N., Ekbal, A., and Kurohashi, S. (2018). "Deep Learning Approach towards Multi-label Classification of Crisis Related Tweets". In: *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management*. ISCRAM 2018. Rochester, NY.

Alam, F., Joty, S., and Imran, M. (2018). "Domain Adaptation with Adversarial Training and Graph Embeddings". In: *56th Annual Meeting of the Association for Computational Linguistics*. ACL 2018.

Alam, F., Ofli, F., and Imran, M. (2018a). "CrisisMMD: Multimodal Twitter Datasets from Natural Disasters". In: *Proc. of the International AAAI Conference on Web and Social Media*. ICWSM. Stanford, California, USA.

Alam, F., Ofli, F., and Imran, M. (2018b). "Processing Social Media Images by Combining Human and Machine Computing during Crises". In: *International Journal of Human-Computer Interaction* 34.4, pp. 311–327.

Bang, D. and Shim, H. (2018). "Improved Training of Generative Adversarial Networks Using Representative Features". In: *Proceedings of the 35th International Conference on Machine Learning*. Ed. by J. Dy and A. Krause. Vol. 80. Proceedings of Machine Learning Research. Stockholmsmässan, Stockholm Sweden: PMLR, pp. 433–442.

Ben-David, S., Blitzer, J., Crammer, K., and Pereira, F. (2007). "Analysis of representations for domain adaptation". In: *Advances in neural information processing systems*, pp. 137–144.

Bica, M., Palen, L., and Bopp, C. (2017). "Visual Representations of Disaster". In: *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*. CSCW '17. Portland, Oregon, USA, pp. 1262–1276.

Bromley, J., Guyon, I., LeCun, Y., Säckinger, E., and Shah, R. (1993). "Signature Verification Using a "Siamese" Time Delay Neural Network". In: *Proceedings of the 6th International Conference on Neural Information Processing Systems*. NIPS'93. Denver, Colorado: Morgan Kaufmann Publishers Inc., pp. 737–744.

Caragea, C., Silvescu, A., and Tapia, A. H. (2016). "Identifying Informative Messages in Disasters using Convolutional Neural Networks". In: *13th Proceedings of the International Conference on Information Systems for Crisis Response and Management, Rio de Janeiro, Brasil, May 22-25, 2016.*

Derczynski, L., Meesters, K., Bontcheva, K., and Maynard, D. (2018). "Helping Crisis Responders Find the Informative Needle in the Tweet Haystack". In: *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2018)*. Rochester, NY.

Enenkel, M., Saenz, S. M., Dookie, D. S., Braman, L., Obradovich, N., and Kryvasheyeu, Y. (2018). "Social Media Data Analysis and Feedback for Advanced Disaster Risk Management". In: *Social Web in Emergency and Disaster Management*.

Frej, W. (2018). "Hurricane Florence Flood Victims Turn To Social Media For Rescue". In: *HuffPost, 2018-09-14, Available at* https://www.huffingtonpost.com/entry/hurricane-florence-flood-victims-social-media_us_5b9b86c0e4b013b097799cd1.

Ganin, Y., Ustinova, E., Ajakan, H., Germain, P., Larochelle, H., Laviolette, F., Marchand, M., and Lempitsky, V. (2016). "Domain-adversarial training of neural networks". In: *JMLR* 17.1, pp. 2096–2030.

Ghifary, M., Kleijn, W. B., Zhang, M., Balduzzi, D., and Li, W. (2016). "Deep reconstruction-classification networks for unsupervised domain adaptation". In: *European Conference on Computer Vision*. Springer, pp. 597–613.

Goodfellow, I., Pouget-Abadie, J., Mirza, M., Xu, B., Warde-Farley, D., Ozair, S., Courville, A., and Bengio, Y. (2014). "Generative adversarial nets". In: *Advances in neural information processing systems*, pp. 2672–2680.

Gopalan, R., Li, R., and Chellappa, R. (2011). "Domain adaptation for object recognition: An unsupervised approach". In: *Computer Vision (ICCV), 2011 IEEE International Conference on*. IEEE, pp. 999–1006.

He, K., Zhang, X., Ren, S., and Sun, J. (2016). "Deep residual learning for image recognition". In: *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 770–778.

Huang, Q. and Xiao, Y. (2015). "Geographic situational awareness: mining tweets for disaster preparedness, emergency response, impact, and recovery". In: *ISPRS Int. Journal of Geo-Information* 4.3, pp. 1549–1568.

Imran, M., Chawla, S., and Castillo, C. (2016). "A Robust Framework for Classifying Evolving Document Streams in an Expert-Machine-Crowd Setting". In: *Proc. of the 18th Int. Conf. on Data Mining (ICDM)*. Barcelona, Spain.

Krizhevsky, A., Sutskever, I., and Hinton, G. E. (2012). "Imagenet classification with deep convolutional neural networks". In: *Advances in neural information processing systems*, pp. 1097–1105.

Kryvasheyeu, Y., Chen, H., Obradovich, N., Moro, E., Van Hentenryck, P., Fowler, J., and Cebrian, M. (2016). "Rapid assessment of disaster damage using social media activity". In: *Science advances* 2.3.

Lagerstrom, R., Arzhaeva, Y., Szul, P., Obst, O., Power, R., Robinson, B., and Bednarz, T. (2016). "Image Classification to Support Emergency Situation Awareness". In: *Frontiers in Robotics and AI* 3, p. 54.

Li, H., Caragea, D., Caragea, C., and Herndon, N. (2017). "Disaster Response Aided by Tweet Classification with a Domain Adaptation Approach". In: *Journal of Contingencies and Crisis Management (JCCM), Special Issue on HCI in Critical Systems.* 26.1, pp. 16–27.

Li, X., Zhang, H., Caragea, D., and Imran, M. (2018). "Localizing and Quantifying Damage in Social Media Images". In: *IEEE/ACM Int. Conf. on Advances in Social Networks Analysis and Mining (ASONAM)*, pp. 194–201.

Long, M., Cao, Y., Wang, J., and Jordan, M. I. (2015). "Learning Transferable Features with Deep Adaptation Networks". In: *Proceedings of the 32Nd International Conference on International Conference on Machine Learning - Volume 37*. ICML'15. Lille, France: JMLR.org, pp. 97–105.

MacMillan, D. (2017). "In Irma, Emergency Responders' New Tools: Twitter and Facebook". In: *The Wall Street Journal, 2017-09-11, Available at https://www.wsj.com/articles/for-hurricane-irma-information-officials-post-on-social-media-1505149661*.

Mazloom, R., Li, H., Caragea, D., Imran, M., and Caragea, C. (2018). "Classification of Twitter Disaster Data Using a Hybrid Feature-Instance Adaptation Approach". In: *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2018)*. Rochester, NY.

Mouzannar, H., Rizk, Y., and Awad, M. (2018). "Damage Identification in Social Media Posts using Multimodal Deep Learning". In: *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2018)*. Rochester, NY.

Neppalli, V. K., Caragea, C., and Caragea, D. (2018). "Deep Neural Networks versus Naïve Bayes Classifiers for Identifying Informative Tweets during Disasters". In: *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2018)*. Rochester, NY.

Nguyen, D. T., Ofli, F., Imran, M., and Mitra, P. (2017). "Damage Assessment from Social Media Imagery Data During Disasters". In: *Proceedings of the 2017 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining 2017*. ASONAM '17. Sydney, Australia: ACM, pp. 569–576.

Nguyen, D. T., Alam, F., Ofli, F., and Imran, M. (2017). "Automatic image filtering on social networks using deep learning and perceptual hashing during crises". In: *Proceedings of the 14th International Conference on Information Systems for Crisis Response and Management*. ISCRAM 2017. Albi, France.

Nguyen, D. T., Al-Mannai, K., Joty, S. R., Sajjad, H., Imran, M., and Mitra, P. (2017). "Robust Classification of Crisis-Related Data on Social Networks using Convolutional Neural Networks". In: *11th International AAAI Conference on Web and Social Media*. ICWSM 2017. Montreal, CA.

Pan, S. J. and Yang, Q. (2010). "A survey on transfer learning". In: *IEEE Transactions on knowledge and data engineering* 22.10, pp. 1345–1359.

Rhodan, M. (2017). "'Please Send Help.' Hurricane Harvey Victims Turn to Twitter and Facebook". In: *Time, 2017-08-30, Available at http://time.com/4921961/hurricane-harvey-twitter-facebook-social-media/*.

Sen, A., Rudra, K., and Ghosh, S. (2015). "Extracting situational awareness from microblogs during disaster events". In: *Communication Systems and Networks (COMSNETS), 2015 7th International Conference on*. IEEE, pp. 1–6.

Simonyan, K. and Zisserman, A. (2014). "Very deep convolutional networks for large-scale image recognition". In: *arXiv preprint arXiv:1409.1556*.

Van Der Maaten, L. (2014). "Accelerating t-SNE using tree-based algorithms." In: *Journal of machine learning research* 15.1, pp. 3221–3245.

Vieweg, S., Hughes, A. L., Starbird, K., and Palen, L. (2010). "Microblogging during two natural hazards events: what twitter may contribute to situational awareness". In: *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, pp. 1079–1088.

Villegas, C., Martinez, M., and Krause, M. (2018). "Lessons from Harvey: Crisis Informatics for Urban Resilience". In: *Rice University Kinder Institute for Urban Research*.

Wang, M. and Deng, W. (2018). "Deep visual domain adaptation: A survey". In: *Neurocomputing* 312, pp. 135–153.

Yarowsky, D. (1995). "Unsupervised Word Sense Disambiguation Rivaling Supervised Methods". In: *Proceedings of the 33rd Annual Meeting on Association for Computational Linguistics*. ACL '95. Cambridge, Massachusetts: Association for Computational Linguistics, pp. 189–196.

Integrating Social Media into a Pan-European Flood Awareness System: A Multilingual Approach

Valerio Lorini
European Commission, Joint Research Centre (JRC), Ispra, Italy
Universitat Pompeu Fabra, Barcelona, Spain
valerio.lorini@ec.europa.eu

Carlos Castillo
Universitat Pompeu Fabra, Barcelona, Spain
chato@acm.org

Francesco Dottori
European Commission, Joint Research Centre (JRC), Ispra, Italy
francesco.dottori@ec.europa.eu

Milan Kalas
KAJO, Bytca, Slovakia
milan.kalas@kajoservices.com

Domenico Nappo
European Commission, Joint Research Centre (JRC), Ispra, Italy
domenico.nappo@gmail.com

Peter Salamon
European Commission, Joint Research Centre (JRC), Ispra, Italy
peter.salamon@ec.europa.eu

ABSTRACT

This paper describes a prototype system that integrates social media analysis into the European Flood Awareness System (EFAS). This integration allows the collection of social media data to be automatically triggered by flood risk warnings determined by a hydro-meteorological model. Then, we adopt a multi-lingual approach to find flood-related messages by employing two state-of-the-art methodologies: language-agnostic word embeddings and language-aligned word embeddings. Both approaches can be used to bootstrap a classifier of social media messages for a new language with little or no labeled data. Finally, we describe a method for selecting relevant and representative messages and displaying them back in the interface of EFAS.

Keywords

Social Media, Disaster Risk Management, Flood Risk

INTRODUCTION

Over millennia humans have developed villages and cities near water bodies, mainly for two reasons: (i) improvements in agricultural yields due to yearly floods in fertile floodplains leaving nutrient-rich silt deposits behind; and (ii) people's desire to live near coastlines and river valleys, often on wetlands and backfilling otherwise natural flood buffers. Due to the closeness of human settlements to rivers and coasts, floods are the natural disasters with the greatest damage potential and the ones that affect the greatest number of people (UN Office for the Coordination of Humanitarian Affairs 2017).

According to recent studies, Global warming is linked to a substantial increase in flood risk over most countries in Central and Western Europe, even if the temperature increases remain close to the lower estimates. For instance, flood peaks with magnitude as it happens once in 100 years, called 'return period', are projected to double in frequency within the next three decades (Alfieri et al. 2015).[1]

[1]The return period of an event is the time span it would take to observe one such event on expectation.

In Europe, the Emergency Response Coordination Centre (ERCC), operating within the European Commission's Civil Protection and Humanitarian Aid Operations department, was set up to support a fast and coordinated response to disasters both inside and outside Europe using resources from the countries participating in the EU Civil Protection Mechanism. This centre monitors hazards and risks, collects and analyzes real-time information on disasters, prepares plans for the deployment of experts, teams and equipment, and in general coordinates the EU's disaster response efforts.

The European Flood Awareness System (EFAS) provides real-time information and forecasts about floods to the ERCC as well as to a series of partners including national and regional hydrological services. EFAS is part of the Copernicus Emergency Management Service (Copernicus EMS), and holds regularly updated flood-related information such as probabilistic medium-range flood forecasts (including short-range flash floods), seasonal forecasts, and impact assessments and early warnings.

Current flood hazard mapping methodologies, such as the one implemented in EFAS, have high scale spatial resolution capacity: 1×1 kilometer resolution globally and 100×100 meter resolution in Europe (Dottori, Salamon, et al. 2016). This combined with state-of-the-art forecasting models provide detailed information about the risk associated with a flood in terms of likelihood, magnitude, timing, and impact (Dottori, Kalas, Salamon, et al. 2017).

Due to nature of floods phenomena and its dynamics, it is important that satellites can monitor the flood extent during the flood peak, therefore early warnings are important to allow sufficient lead time for requesting satellite mappings of the area at risk (Dottori, Kalas, Lorini, et al. 2017).

Over the past decade, social media has emerged as a relevant information source during disasters, prompting researchers from diverse areas to converge on this domain (Castillo 2016; Palen and Anderson 2016). Social media analysis has demonstrated the potential to provide timely, precious information about the spatial (Brouwer et al. 2017; Restrepo-Estrada et al. 2018) and temporal (Vieweg et al. 2014) development of a crisis, as well as supporting the identification of key disaster-related events (Musaev et al. 2015). Although the value of social media analysis in providing timely data and methods for the analysis of natural hazards has been recognized in previous work, comparatively much less attention has been given to how to integrate social media in a seamless, reliable way with tools for disaster forecasting and monitoring.

Since the geographical domain of EFAS products covers an area where population speaks more than 27 languages, we focused on a multi-lingual system. We therefore use representation of words as vectors in order to exploit probabilistic functions to infer similarities between words, know as word embeddings(Pennington et al. 2014).

Our research fills this gap by describing the integration of social media monitoring into a flood monitoring and forecasting platform, enriching hydro-meteorological information with reports from the public.

We developed software for EFAS named Social Media for Flood Risk (SMFR) which provides near-real-time information collected from social media about flood risks and impacts, including examples of messages in social media about it. Figure 1 represents the conceptual schema of SMFR's components, part of which is described in this paper, and their integration.

Our main contributions are:

- We integrate social media data collection into the European Flood Awareness System (EFAS) based on EFAS forecasts. Whenever EFAS rapid risk assessment identifies heightened risk of floods in a certain area, we trigger data collection from social media (in our case, Twitter) respecting API limitations while dealing with the possibility of various events happening at the same time. A similar mechanism is already in use for triggering pre-tasking of satellite image acquisition in Copernicus EMS
- We describe a methodology that requires a minimal amount of manual intervention for each additional language, and demonstrate it with four languages being used to bootstrap a classifier for a fifth language. This methodology is based on Convolutional Neural Networks and its multi-lingual capabilities stem from using either language-agnostic word embeddings, where vectors representing sentences are not dependent on a single language, or multi-lingual word embeddings (Conneau et al. 2017).
- We describe an aggregation and selection module that can select representative messages for an area in which flood risk has been predicted.
- We integrate SMFR into EFAS and demonstrate it during the recent floods affecting Calabria, Italy, in early October 2018. Note that we decided to present only one case for the sake of clarity and conciseness, however SMFR has been tested with additional real cases.

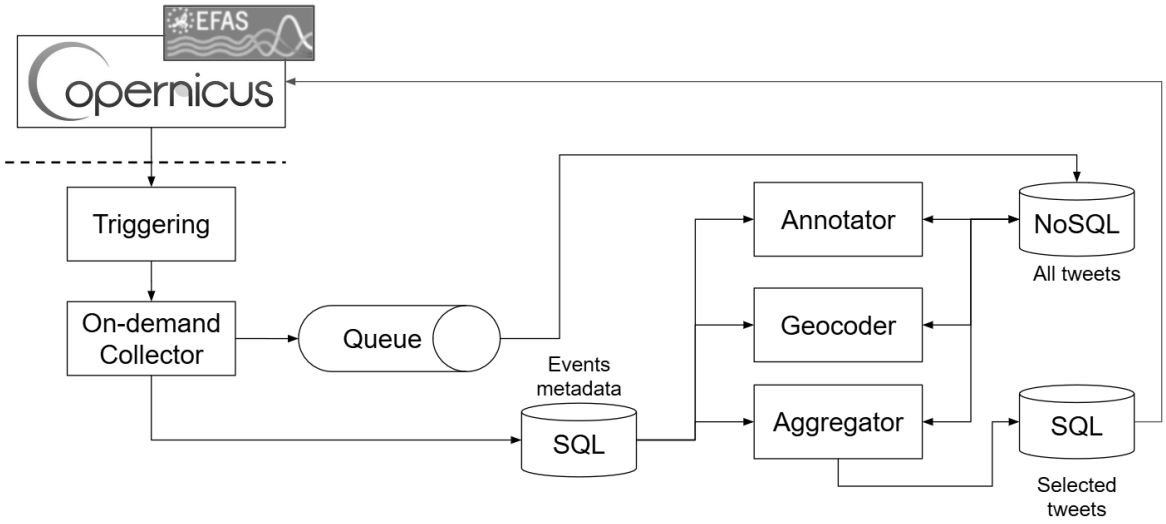


Figure 1. Schema of SMFR components

The remainder of this paper is organized as follows: the next section presents related work; then, three technical sections describe the methods for on-demand data collection, multi-lingual classification, and aggregation and selection. Finally, we present experimental results, including a case study, followed by our conclusions and future work.

RELATED WORK

Background: European Flood Awareness System (EFAS)

EFAS is part of the Copernicus Emergency Management Systems, and serves the ERCC and EU member states' Civil Protection agencies with forecasts of flood risks. It covers the European Union as well as several neighbouring areas that are relevant from the perspective of flood risk and EU policies (e.g. all countries of the Danube river basin). EFAS provides information based on weather forecasts[2] and hydrological ensemble predictions obtained by an hydrological model simulations, therefore subjected to uncertainty. For being exploited at its maximum potential it should offer additional supporting information that could be used for prioritizing resources and interventions. EFAS already includes products that go in that direction. For instance pre-tasking satellite mappings is triggered in advance integrating socio-economic data (population, infrastructures, economic losses fused as impact indicators) with flood magnitude and probability (likelihood)(Dottori, Kalas, Lorini, et al. 2017).

EFAS forecasts have good accuracy level which is constantly monitored[3], but Crisis are only declared, formalised and managed by the local authorities and it's up to them to decide what to do with the data provided. The new layer presented helps in the near real time confirmation of floods for areas where a high flood risk was forecasted. The SMFR layer includes a set of representative tweets and a dot distribution map of social media messages related to floods.

Combining authoritative and non-authoritative data

A recent trend in research on social media on disaster has been to study methodologies for combining non-authoritative and authoritative data in risk assessment. The non-authoritative data are reports generated by the public, typically posts in social media platforms. The authoritative data comes from various sensors including meteorological and hydrological ones as well as physical models for creating forecasts with this data. In previous work, these data have been combined in various ways.

Musaev et al. (2015) describe the LITMUS platform, which collects and filters messages about landslides from various social media platforms and geo-locates them to merge reported events with data from physical sensors referring to the same location.

[2]EFAS inputs are based on the Ensemble Prediction System from the European Center for Medium Range Weather Forecast (ECMWF) which consists of 51 ensemble member.

[3]publicly available at https://www.efas.eu/validation-and-skill-scores

Brouwer et al. (2017) use social media combined with authoritative data to define probabilistic and deterministic flood-extent maps. Information gathered from the public is used to make inferences about rainfall, contributing to interpolate coarse-grained data at a the same resolution as a Local Drainage Direction (LDD) map, in order to determine water levels for different cells.

Restrepo-Estrada et al. (2018) use a transformation function for creating a proxy variable for rainfall by analyzing keywords-filtered geo-located social media messages and rainfall measurements from authoritative sources. The proxy variable is incorporated in a hydrological model for stream-flow estimation.

Our work differs from the previous ones in important ways. First, we do not filter social media posts by flood-related keywords, but rather according to the location of a possible flood based on forecasts from the EFAS system. Second, we aggregate data using a geocode standard for referencing the subdivisions of countries for statistical purposes, known as Nomenclature of Territorial Units for Statistics(EC 2016). Its granularity is identified by levels, the higher the level, the higher the granularity. In our work we used level 2 (NUTS-2) as the main subdivision. Third, we cover a large area by automatically processing content in several languages. The goal of our system is to confirm and bring more detail to the outcomes of an hydrological model.

Multi-lingual classification of social media postings

SMFR is designed to work across multiple languages. The main processing that we do to messages is to determine whether they are relevant to flood risks/impacts or not. This is done through supervised classification, which requires labeled data. However, to work across multiple languages in practice requires to be able to classify messages in languages for which we may not have labeled data yet.

Past research addressed cross-lingual bootstrapping of classifiers for natural disasters detection on twitter (Middleton et al. 2013) relying on automatic translation to use available models. Previous works, such as Li et al. (2018) has shown how an approach based on *word embeddings* works better than a simpler method based on bag-of-words when generalization is critical, including our case which requires generalizing across languages. Khare et al. (2018) built a statistical-semantic classification model with semantics extracted from BabelNet and DBpedia and compared relevancy classifiers with datasets translated into a single language, as well as with cross-lingual datasets. They have shown how adding semantics increases cross-lingual classification accuracy.

Our work, in contrast, does not require semantic resources, we only leverage on word embeddings for multi-lingual modelling as demonstrated by Luong et al. (2015). Indeed, we present and demonstrate two different ways in which word embeddings can be used to perform multi-lingual classification: using language-agnostic word embeddings learnt from a multi-lingual corpus (Pennington et al. 2014), and using multi-lingual word embeddings that are aligned across languages (Conneau et al. 2017). In both cases, we can use labeled data in a set of known languages to bootstrap a classifier for a new language for which no labels are available.

ON-DEMAND DATA COLLECTION

The data collection should ideally achieve high recall, capturing a large fraction of the relevant information, while at the same time having high precision, avoiding irrelevant information. Both goals usually enter into conflict and trade-offs are necessary. Previous research has described extensively how data collection from Twitter is done (see, e.g., Imran, Castillo, Diaz, et al. 2015), in this section we focus on the specific aspects of our system, which performs *on-demand data collection*.

The key element of our data collection is its triggering mechanism which is done dynamically according to flood forecasts. EFAS runs two simulations per day, identifying NUTS-2 areas (typically regions or provinces) where there is a high probability of floods impacts in the following 48 hours as shown in figure 2.

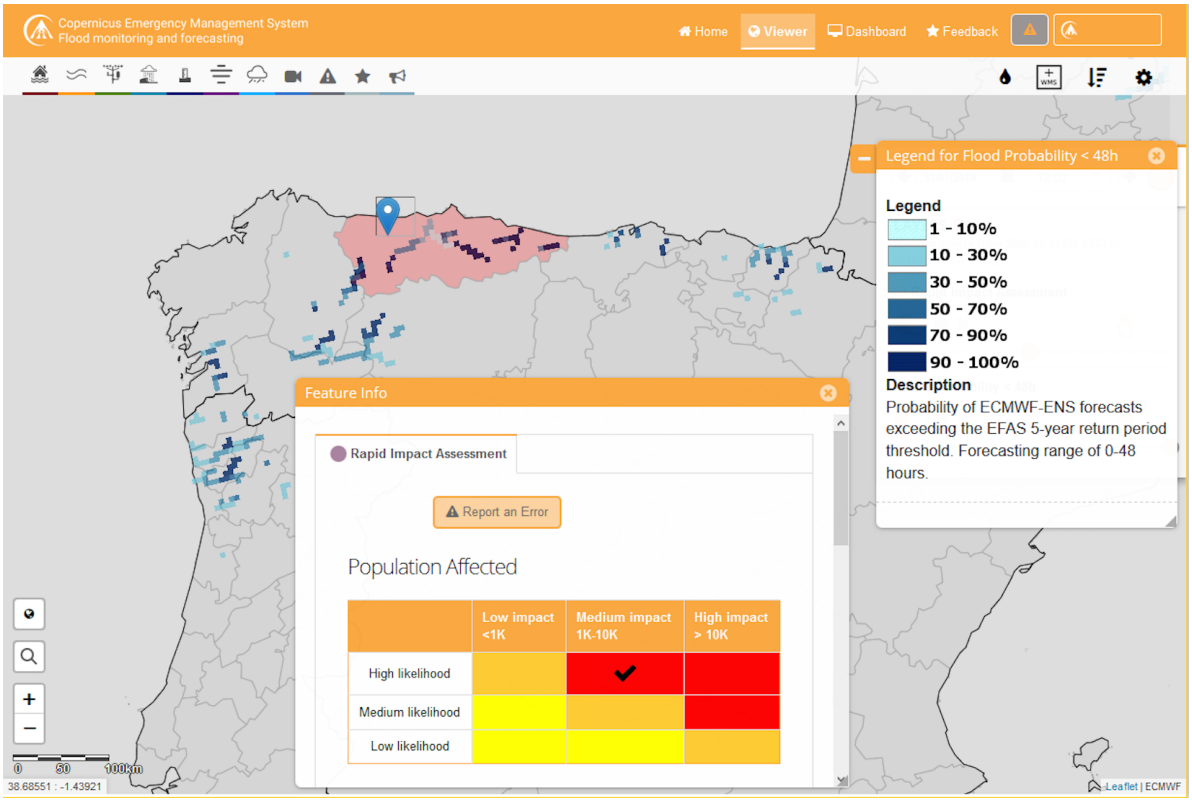


Figure 2. Screenshot of EFAS web interface with the layers identifying areas where there is high probability of floods in the following 48 hours and rapid impact assessment

Once the list of NUTS-2 areas is received, the system extracts their coordinates and the names of all cities in the area that have more than a certain number of inhabitants. The coordinates are used for filtering the Tweets by location while the names of cities, in english and local language, translate into a series of 'OR' filters by keywords. In our current configuration, we set this threshold empirically to 80,000 inhabitants, which tends to capture a handful of cities for each event. A lower threshold is possible as long as it does not generate a large number of city names that exceeds Twitter's API limitations.

Given the limitations in Twitter's API, we use a single connection against Twitter's public streamer at any given time. Additionally, the public streamer limits queries to up to 400 keywords (each of less than 60 bytes) and up to 25 location rectangles.[4] A *query builder* component groups several active events in order to update a single request respecting these limitations, while keeping information about the single possible event identified by EFAS. Each collection is kept active for two days after the expected peak time. If the peak time estimation is updated by a new EFAS simulation, the collection's expiration time is extended. Given that we have a single query, SMFR has to separate the incoming stream into different events according to locations and keywords. If a message belongs to overlapping regions or contains names of cities in different events, the message is copied to all the matching events.

Figure 3 depicts how rapid risk assessment leads to the definition of a series of keywords (city names) and locations (rectangles containing NUTS-2 areas) for filtering information from Twitter's public streamer. The areas in yellow and red in the figure are identified as having high risk of flood by EFAS. Then, the system determines names of cities in each area and bounding boxes surrounding each area. We have heuristics that merge neighboring areas and de-prioritize smaller cities if their quantity exceeds Twitter's limitations, but in practice these are rarely triggered.

[4] https://developer.twitter.com/en/docs/tweets/filter-realtime/overview accessed November 2018.

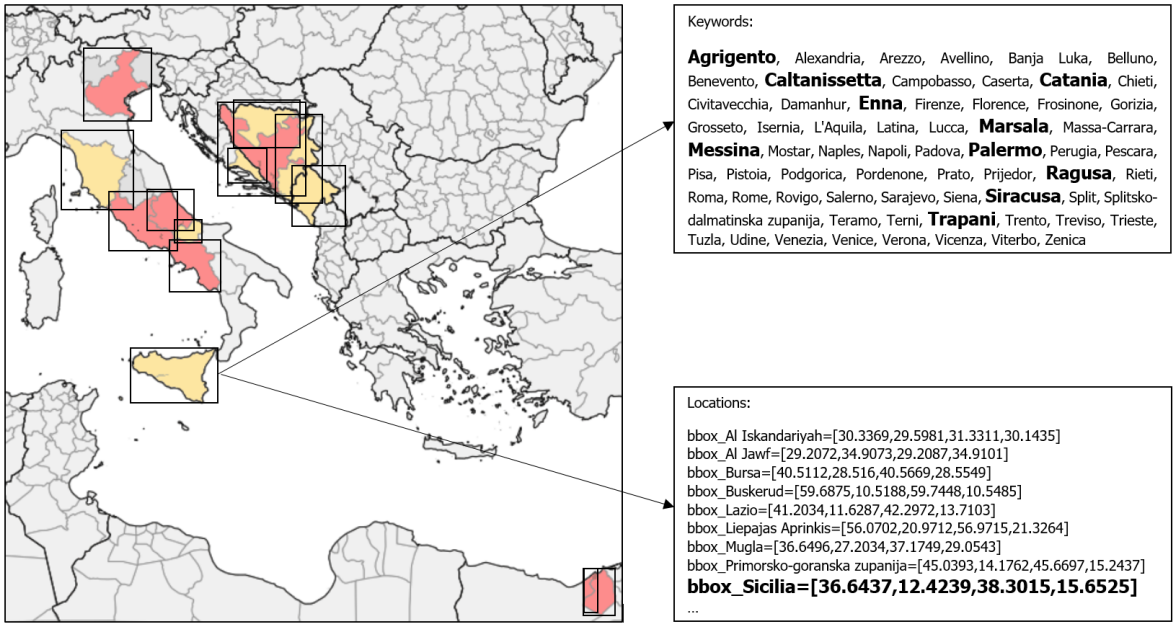


Figure 3. Example depicting areas in which EFAS forecasts high risk, which appear in yellow and red color. Each area defines a set of keywords, which are names of cities, and locations, which are bounding boxes (rectangles). These keywords and locations are used to gather information from Twitter.

MULTI-LINGUAL CLASSIFICATION

The setting used was supervised binary classification. The positive class comprised all messages indicating that "a flood has just happened or is about to happen" while the negative class included all other messages.

Training data was labeled using crowdsourcing platform GetHybrid (https://gethybrid.io/). The amount of labeled data comprises over 7,000 annotated messages, each one annotated by three annotators independently. Four training datasets were created, containing labeled tweets in German, English, Spanish, and French. Each language includes between 1,200 and 2,300 annotated messages, as shown in Table 1 (column "TL" for Total Labeled) in the section describing the experiments. This amount of data is typical in automatic classification tasks (Imran, Castillo, Diaz, et al. 2015).

Convolutional Neural Networks

We tested a number of learning algorithms, including Support Vector Machines (Joachims 1999), which have been shown to be effective for a number of general text classification tasks, and Random Forests, which have been shown to be effective specifically for classifying crisis-related Twitter messages (Imran, Castillo, Lucas, et al. 2014). In both cases, we represented messages as bag of word unigrams and bigrams, and the performance was better than simpler methods such as a naïve Bayes classifier or a decision tree.

A comparatively newer approach for text classification that has proven to be quite effective is the use of Convolutional Neural Networks (CNN). These have been employed for a number of tasks including sentiment analysis (Severyn and Moschitti 2015).

There are four main operations in every Convolutional Neural Network:(i) Convolution; (ii) Non Linearity, Rectified Linear Unit (ReLU); (iii) Pooling or Sub Sampling;(iv) Classification (Fully Connected Layer). The primary purpose of (i) Convolution is to extract features from the input using a filter smaller in size than the original input. The second (ii) operation ReLU replaces all negative values in the feature map by zero. The (iii) Pooling operation , max pooling in our case, reduces dimensionality by taking the largest element from the rectified feature map within a neighborhood. The (iv) Classification operations, after a series of iteration of the (ii) and (iii) then uses the higher-level features identified to deter a class using several fully connected perceptrons layers.

A Support Vector Machine (SVM) is a classifier defined by a separation hyperplane. Input of the algorithm is the labeled training data, while its output is an optimal hyperplane which places new data into distinct classes.

Random forest classifiers infer a series of decision trees from randomly selected subset of the labeled data. The results are then passed through different decision trees to finally classify the test data.

The specific architecture we used is described in the next section; using it, we performed various experiments using 10-20 epochs of training (passes over the entire training set in randomised order).

The results were similar in performance to the SVM and Random Forests. However, manual error analysis showed that qualitatively these errors were different. While in the case of SVM and Random Forests a misclassification, such as a false positive, is usually the result of a word marking flood relevance (e.g., "flood") used in a completely different context (e.g., "my timeline is flooded with messages"), in the case of the neural network we used a misclassification was often semantically related to floods, such as a message referring to the effects of other natural disasters. The lesson learned from these experiments was that neural networks are better in this problem at capturing semantic characteristics that are relevant for our task of distinguishing flood-related messages.

Neural Network Architecture

Current implementations of convolutional neural networks for text processing tasks tend to have a similar architecture. They consist of an input layer, a word embedding layer, a series of convolutional and max pooling layers, a dense layer, and an output layer (Liao 2016).

The input layer holds a padded sequence of words with a maximum length $S = 100$ words, which is more than sufficient for tweets considering their maximum length is 280 characters.

The word embedding layer converts every word into a low-dimensional vector, typically in the order of a few hundred dimensions (e.g., $D = 200$ or $D = 300$). We used two sources of pre-trained word embeddings, as described in the next section. For each pre-trained word embedding, we considered two configurations-ups: one in which the parameters of the pre-trained word embedding were fixed, i.e., not modifiable while training the neural network, and one in which they were part of the optimization process, i.e., modifiable while training. In our experiments, best results were obtained when these parameters were fixed, probably because the amount of flood-specific data that we are using for training is small in comparison with the corpora used to create these word embeddings. The results we report on this paper use fixed word embeddings.

The convolution layers collect several word embeddings representing adjacent words and “summarize” them into a single vector. The main parameter for the convolutions is the width C, which is how many adjacent words to take into account. In the text "flood warning due to heavy rain" using $C = 5$, there are two possible convolutions: “flood warning due to heavy” and “warning due to heavy rain.” The parameter C is determined considering what is the effect of the context on the meaning of a word, and $C = 5$ is a typical value. We did not observe any increase in performance with a larger value of C, while a smaller value of C may lose contextual information.

The max pooling layer collect a series of m disjoint convolutions as input, and generate a vector of dimension $d < D$ as output. The max pooling step operates differently from the convolution layers in the sense that the windows it uses are disjoint, i.e., non-overlapping. The purpose of this layer is to reduce the dimensionality of the network for computational purposes and to reduce the chances of overfitting. In our case we used $m = 5$ and $d = 128$, which are typical parameters used in text classification.

The final layer is a densely-connected (complete) layer. All the neurons in the last max pooling layer are connected to all the neurons in this dense layer, and all the neurons in this dense layer are connected to the two output neurons. One of the two output neurons should activate when the example is positive (i.e., a message indicating that a flood has just happened or is about to happen), and the other output neuron should activate when the example is negative (i.e., the message does not indicate that a flood has just happened or is about to happen).

Word Embeddings for Multi-Lingual Classification

The usage of word embeddings allows to incorporate multi-lingual capabilities in two ways: by using language-agnostic word embeddings and by using language-aligned word embeddings.

Our source of language-agnostic word embeddings is GloVe (Pennington et al. 2014), which are vectors of dimensionality 200 obtained from a large corpus of tweets containing 27×10^9 tokens (1.2 million of them unique). While these word embeddings were not developed for multi-lingual tasks, they do incorporate any word present on a tweet in a language-agnostic manner.

Our source of language-aligned word embeddings is MUSE (Conneau et al. 2017), which are vectors of dimensionality 300 obtained from various snapshots of Wikipedia in various languages. For each language, vectors for the 200,000

most frequent tokens are provided, and these vectors have been *aligned* across languages using parallel lists of tens of thousands of words. In the resulting embeddings, two words with the same meaning in different languages are mapped to similar vectors.

In our experiments, presented on the next section, both pre-trained sets of vectors allow to transfer an automatic classifier learnt with labeled data from one language (or a set of languages) into another language with no new labeled data ("cold start") or with a limited amount of labeled data ("warm start").

AGGREGATION AND SELECTION

In our integration with EFAS, flood risk is established by an hydro-meteorological model and our task is to add complementary information that brings a better understanding of the situation on the ground. Relevant messages are mapped to NUTS-2 areas (Nomenclature of Territorial Units for Statistics, Level 2) either by using explicit coordinates which are rarely present in tweets, or more often, via a text-based geocoder. Geocoding deals with messages that do not include explicit geographical coordinates, but mention a place name such as landmark or city. Geocoding uses a Named Entity Recognition tagger to obtain possible locations in a text considering the syntax of the message. It uses a gazetteer in a large database of place names with their corresponding geographical coordinates, and finally it uses a neural networks to infer the correct country and correct gazetteer entry for those places. We used a library named Mordecai (Halterman 2017) which extracts place names from a piece of text, resolve them to the correct place, and return their coordinates and structured geographic information.

Messages are aggregated at the level of an event, but also at the level of each NUTS-2 area. In both cases, one key operation is to select a representative sub-set of messages. We do this operation by using the following efficient heuristic based on de-duplication and text centrality:

1. Select up to 5,000 tweets having at least a 90% probability of being flood-related; if there are more than 5,000 tweets, select the ones with the highest probability
2. Compute similarities between these tweets
   (a) Consider only pairs having probabilities of being flood-related that differ at most by 0.0001, exploiting the fact that near-duplicate tweets will be given the same probability by the neural network
   (b) Compute edit distance and use it to compute normalized similarity: $1 - \ell(m_1, m_2)/(|m_1| + |m_2|)$ where $\ell(m_1, m_2)$ is the edit distance between the two messages and $|m_1| + |m_2|$ the sum of their lengths.
   (c) If the normalized similarity is greater than 0.8, use the timestamps of the tweets to mark the newer tweet as a duplicate of the older tweet
3. Sort all unique tweets by their *multiplicity*, i.e., by the number of duplicates they have, and keep the top 100
4. For these tweets, compute all pair-wise similarities using the same formula as above, and add the similarities for every tweet; this is the *centrality* of the tweet.

Step 1 of the heuristic has the goal of removing messages that are irrelevant. Step 2 removes near-duplicates which are redundant, but keeps track of how many near-duplicates a tweet has, for the purposes of using redundancy as a signal of importance. Step 3 applies a well-known lexical centrality heuristic (Erkan and Radev 2004), in which a salient message is one that has content in common with many other messages.

Figure 4 shows a first deployment of SMFR on EFAS web interface, it describes how the areas and their most relevant tweets are presented to EFAS users. The NUTS-2 area can be grey (low activity), orange (medium activity) or red (high activity) according to the ratio between numbers of annotated tweets. The triggering that lead to the creation of the collection depicted can be seen in figure 2

EXPERIMENTAL RESULTS

We describe two types of experimental results. First, we perform experiments to test the performance of the multilingual-classifier, comparing it with a mono-lingual classifier. Second, we show a real example of an actual flood event, describing the performance of the on-demand collector, of a multi-lingual classifier that does not use labeled data from the target language, and of the aggregation and selection method.

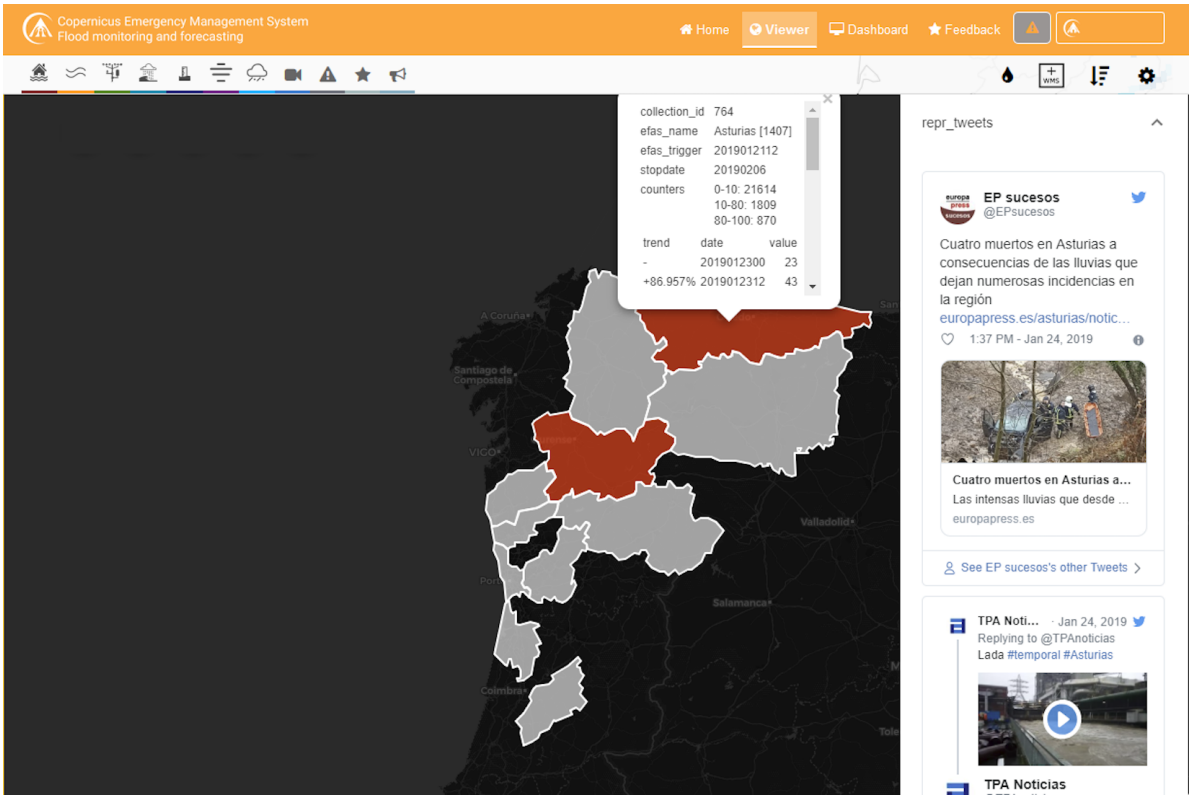


Figure 4. Screenshot of EFAS web interface with the layer identifying areas where there is high tweet activity and their most representative tweets on the right side. The basemap has been darkened for better visualization

Multi-Lingual Classifier

The multi-lingual classifier provides a solution for bootstrapping classifiers in new languages based on labeled data for other languages. The aim of the experiments is to compare the classifiers trained with and without labeled data for a specific target language. Performing this evaluation, nevertheless, requires having labeled data to measure effectiveness parameters.

For these experiments we use four labeled sets of flood-related tweets in German (DE), English (EN), Spanish (ES) and French (FR). These were labeled by crowdsourcing workers via crowdsourcing as previously described; the question the annotators had to answer was "is this message indicating that a flood is happening or about to happen?" Hence, positive examples are the ones that are related to flood risk and impact, and negative examples are the ones that are not.

For each language and word-embedding source we performed three experiments: mono-lingual, cold-start, and warm-start. We used two thirds of the labeled data for training the classifiers and the remaining third for testing. We keep the testing portion fixed across experiments.

In the *mono-lingual* experiment we simply use labeled data in one language to predict the label for messages in the same language. In the *cold-start* experiment we train a classifier for a new language using only labeled data for other languages; for instance for automatically labeling tweets in Spanish, we use a classifier trained on labeled data for English, German, and French. In the *warm-start* experiment we use a set-up similar to the one of the cold-start experiment, but we add a limited number of messages (300) labeled in the target language. Each experiment is done once using GloVe embeddings and once using MUSE embeddings. We report precision, recall, and F-measure for each experimental setup in Table 1.

Table 1 reports values for Precision (P) , Recall (R) and F-measure. We also include the total number of tweets manually labeled by crowdsourcing workers (TL) and its percentage of positive (Pos.) tweets. Collections for German, English, Spanish, and French consider tweets posted during floods happening in the last two years in Germany, the UK, Spain and Mexico, and France respectively. Hence, the number of labeled tweets and the percentage of positive examples differ across languages.

All the results show the same pattern: the mono-lingual classifier performs best, as expected; the cold-start classifier (which does not use any labeled data in the target language) suffers from a loss mostly of precision, but also of recall;

Table 1. Classification results for four languages (German, English, Spanish, and French). TL indicates the total number of labeled messages, while Pos. indicates the percentage of those who were labeled as flood-related. P, R, and F indicate Precision, Recall, and F-Measure respectively. We report the performance of a mono-lingual classifier, of a cross-language classifier with "cold start" (uses no training data in the target language), and of a cross-language classifier with "warm start" (uses 300 labeled items in the target language).

			Glove embeddings									MUSE embeddings								
			mono-lingual			cold-start			warm-start			mono-lingual			cold-start			warm-start		
	TL	Pos.	P	R	F	P	R	F	P	R	F	P	R	F	P	R	F	P	R	F
DE	2356	46%	0.95	0.82	0.87	0.59	0.85	0.70	0.93	0.8	0.86	0.88	0.85	0.87	0.54	0.82	0.65	0.89	0.80	0.84
EN	1999	20%	0.79	0.63	0.70	0.59	0.49	0.54	0.67	0.51	0.58	0.64	0.68	0.66	0.33	0.50	0.40	0.58	0.28	0.38
ES	1592	48%	0.80	0.78	0.79	0.61	0.75	0.67	0.71	0.83	0.77	0.70	0.84	0.77	0.62	0.69	0.65	0.68	0.89	0.77
FR	1248	40%	0.74	0.72	0.73	0.50	0.46	0.48	0.62	0.77	0.69	0.69	0.75	0.72	0.44	0.86	0.58	0.59	0.72	0.65

and the warm-start classifier (which involves annotating a small number of tweets in the target language) has better performance than the cold-start classifier both in terms of precision and recall. Indeed, the warm-start classifier often achieves an F-measure that is comparable to the one of the mono-lingual classifier. Regarding the choice of word embeddings, results suggest that the performance using GloVe or MUSE embeddings are comparable.

In general, considering the combination of the information from the classification with the known locations from the EFAS forecasts, the classification performance is sufficient to extract representative tweets from an event and to map approximately the affected locations, as we demonstrate next.

Case Study: Calabria Floods in October 2018

In early October 2018, floods affected the region of Calabria in southern Italy. At least 2 people died in flash flooding after severe weather which peaked on October 5th. A mother and her seven year old son, who were swept away by flood waters in their car, were found in a river near Lamezia Terme, between the towns of San Pietro a Maida and San Pietro Lametino in Calabria. Other areas of Calabria were also hit by flooding and landslides.

Several families were forced to evacuate their homes and people were rescued after they climbed onto the rooftops of houses to escape the flooding.[5] Italian news agency ANSA, stated that the Ponte delle Grazie bridge on provincial highway 19 in the area collapsed during the storms (Redazione ANSA 2018). Vigili del Fuoco, Italy's National Firefighters Corps, reported major flooding in Ciro Marina, Petilia de Policastro, Strongoli, Cotronei and Isola di Capo Rizzuto. As shown in Figure 5 (a) more than 300 mm of rain fell in 3 days (Schiaroli 2018).

EFAS forecasted a potential flood in the Calabria NUTS-2 area on the 4th of October with a predicted peak time of the event for the following day. As planned, SMFR triggered a collection with a duration of 2 days that was later extended for an additional day due to persistence of the signal from EFAS forecasts. We analyzed the collection once it was stopped, at midnight on the 7th of October, after collecting 14,347 tweets.

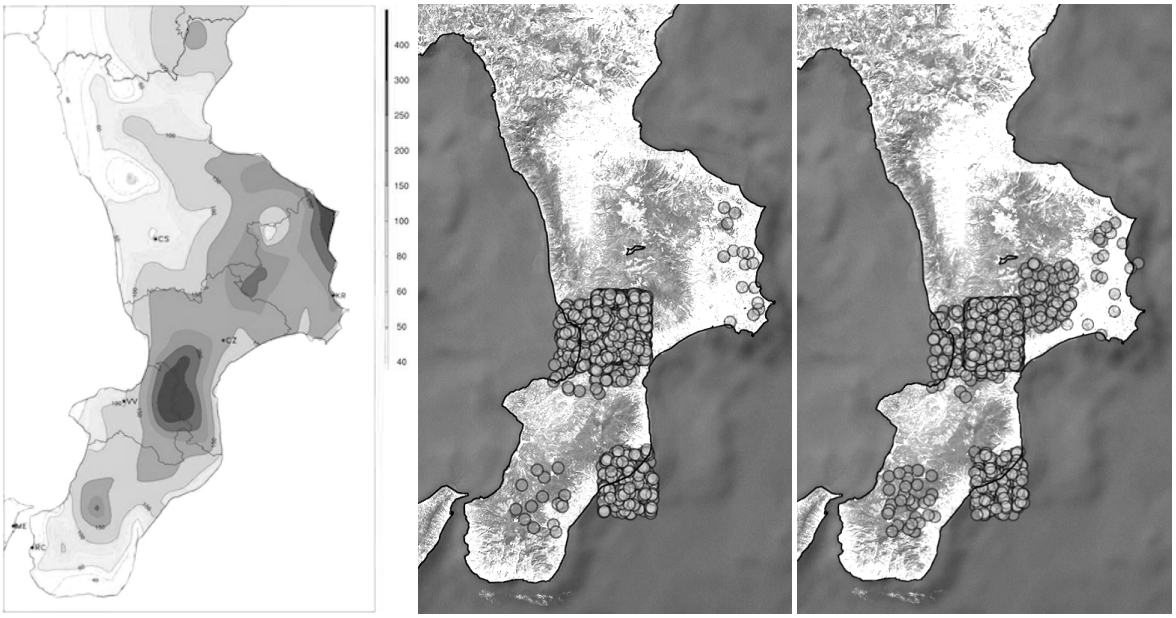
In order to confirm what emerged from experiments in the previous section, we trained two classifiers for messages in Italian, the first (cold-start) using only labeled data in German, English, Spanish, and French, and the second (warm-start) adding 300 manually labeled tweets in Italian from the collected dataset. For brevity we present results obtained using the GloVe embeddings (results using MUSE embeddings are similar).

In Figures 5 (b) and (c) we depict the position of geo-located tweets annotated by the cold-start and warm-start classifier respectively. Tweets have been filtered using a relevance to flood (label predicted) greater or equal to 0.8. We include the tweets geolocated within the bounding box used for triggering the collection, resulting in 2,847 tweets for the cold-start scenario against 3,857 for the warm-start scenario. For visualization purposes, tweets geo-located to the exact same location are randomly scattered by a small amount in the map.

Figure 5 confirms the results from the experiments, in the sense that both cold-start and warm-start classifiers are able to classify relevant tweets, with an advantage for the warm-start classifier in the sense that it identifies more relevant tweets and has better coverage of the areas affected by heavy rainfall. This suggests that the cold-start method can provide a first approximation for identifying an ongoing event, while the warm-start method yields more precise and relevant tweets.

Finally, Table 2 shows samples of tweets that have been selected as the most representative for this event, following the heuristic described previously, and taking as input the tweets found relevant using the cold-start and warm-start methods. We can see that in the cold-start scenario the most representative tweets are relevant to the event considered. However, the warm-start scenario gives more informative messages. While tweets selected by the cold-start classifier

[5]Data provided by floodlist.com, which is a EU-supported project providing reports on past floods.



(a) Rainfall (b) Tweets, cold start (c) Tweets, warm start

Figure 5. Comparison of (a) rainfall, (b) tweets located by cold-start model, and (c) tweets located by warm-start model. Data from floods in Calabria, Italy, 2-5 October 2018. Tweets falling in the same location are randomly scattered for visualization purposes.

are relevant, they mostly just confirm the event as reported in the news; in constrast, the tweets selected in the warm-start case identify a message from the Italian Prime minister as the most representative ("I follow with concern the evolution of events ...") and include information about damages and casualties due to the flood.

Table 2. Representative tweets selected by cold-start and warm-start. Conf. is the confidence of the classifier. Mult. the multiplicity (number of near-duplicates of the tweet). Cent. is the centrality (number of closely related but not duplicate tweets).

Cold-start			
Conf.	Mult.	Cent.	Text (first ~10 words)
1.0	87	89	Second flood in Calabria in 40 days. Devastation and 2 casualties ... *(Seconda inondazione in Calabria in soli 40 giorni. Devastazione e 2 vittime ...)*
1.0	11	93	Bad weather in Calabria, the kennel is flooded ... *(Maltempo in Calabria, il canile e 'sommerso dall' acqua ...)*
1.0	7	94	Bad weather: Red alert in Calabria today and in Puglia tomorrow ... *(Maltempo: oggi allerta rossa in Calabria e domani in Puglia ...)*
1.0	5	97	Meteo, panic in Calabria: streams flooding roads. Rescuers using rubber boats ... *(Meteo, caos in Calabria: torrenti esondati e strade allagate. Soccorsi in gommone ...)*
1.0	5	87	Bad weather in Calabria, missing mother and her two sons found dead ... *(Maltempo Calabria, trovati morti mamma e due bimbi dispersi ...)*
Warm-start			
Conf.	Mult.	Cent.	Text (first ~10 words)
1.0	194	76	I follow with concern the evolution of events in #Calabria ... *(Seguo con apprensione l ' evolversi degli eventi in #Calabria ...)*
1.0	194	88	Water bomb in Calabria, among the upset in the population ... *(Bomba d ' acqua in Calabria, tra la popolazione sconvolta ...)*
1.0	14	46	# breakingnews Bad weather Calabria: a woman and one of her son found dead. ... *(#ultimora Maltempo Calabria: morta una donna e suo figlio, disperso il fratello ...)*
1.0	23	98	Bad weather in Calabria, mom and son found dead, missing 2yrs old brother ... *(Maltempo in Calabria, morti mamma e figlio: sic erca il fratellino di 2 anni ...)*
1.0	8	94	Bad weather, nigthmarish night in Calabria, Civil Protection: "High risk" ... *(Maltempo, notte da incubo in Calabria, Protezione civile: "rischio vittime" ...)*

CONCLUSIONS AND FUTURE WORK

We have described how to integrate social media into the European Flood Awareness System (EFAS) to provide valuable signals augmenting flood risk information provided by this platform, by finding potentially relevant and representative messages from flood-affected areas in the languages spoken in those areas. Our work provides a solution and methodology for integrating flood modeling and evidence from the ground in real-time for several countries, potentially providing information from local witnesses or local media to first responders. This unique combination of hydrological simulation forecasting and an automatic, immediate monitoring of the extent of the event through social media without necessity to manually translating information, allows to shorten the response time, which is extremely precious in the very early stages of a flood. Moreover, during the development of an event, collected messages could be valuable to international rescue coordinators such as ERCC because they provide insights about the local response, about whether alerts that have been issued by authorities, and about some of the concerns that those affected by a flood or a flood alert may have. The research also highlighted the need for high-recall data collection in which data in multiple languages is captured, and provided a methodology for dealing with a new language, by bootstrapping a classifier with similar languages for which labeled data is available, using either language-agnostic or language-aligned word embeddings. Additionally, it was clear during the development of the project that naturally occurring data (i.e., actual messages posted during a flood in a particular country) are necessary to build an accurate classifier and aggregator.

Limitations. Due to the nature of EFAS and its geographical domain (pan-European) we focused on language spoken in the region, therefore we only tested the methodology proposed for indoeuropean languages. The performance with other languages remains to be studied.

At the time of writing, the described system is still in testing phase. After a period of internal evaluation, SMFR will become operational and its results will be disseminated among EFAS Partners.

Future Work

As future research activities, one can envision a global system comprising dozens of languages used to augment the Global Flood Awareness System (GloFAS; http://www.globalfloods.eu/). One can also envision further steps in the direction of using social media as a data source that can feed into a predictive model, using it not only for confirming known flood risks, but also for detecting new ones, particularly in areas where digital devices are prevalent but meteorological stations and other physical sensors are scarce in comparison.

Reproducibility. Datasets and code for the experiments described on this paper will be available for research purposes at https://bitbucket.org/lorinivalerio/iscram_2019/.

ACKNOWLEDGMENTS

This job has been funded by an Exploratory Research grant made available by the Joint Research Centre of the European Commission. Thanks to Gabriele Mantovani Banella and Sasa Vranic for helping in the development of web layers and web services for the integration of SMFR into the existing EFAS/GloFAS systems. Castillo thanks La Caixa project LCF/PR/PR16/11110009 for partial support.

REFERENCES

Alfieri, L., Burek, P., Feyen, L., and Forzieri, G. (May 2015). "Global warming increases the frequency of river floods in Europe". In: *Hydrology and Earth System Sciences Discussions* 12, pp. 1119–1152.

Brouwer, T., Eilander, D., Loenen, A. van, Booij, M. J., Wijnberg, K. M., Verkade, J. S., and Wagemaker, J. (May 2017). "Probabilistic flood extent estimates from social media flood observations". en. In: *Natural Hazards and Earth System Sciences* 17.5, pp. 735–747.

Castillo, C. (July 2016). *Big Crisis Data*.

Conneau, A., Lample, G., Ranzato, M., Denoyer, L., and Jégou, H. (Oct. 2017). "Word Translation Without Parallel Data". en. In: *arXiv:1710.04087 [cs]*.

Dottori, F., Kalas, M., Lorini, V., Wania, A., Pappenberger, F., Salamon, P., Ramos, M. H., Cloke, H., and Castillo, C. (2017). "Satellites, tweets, forecasts: the future of flood disaster management?" In: *EGU General Assembly Conference Abstracts*. Vol. 19, p. 13129.

Dottori, F., Kalas, M., Salamon, P., Bianchi, A., Alfieri, L., and Feyen, L. (July 2017). "An operational procedure for rapid flood risk assessment in Europe". English. In: *Natural Hazards and Earth System Sciences* 17.7, pp. 1111–1126.

Dottori, F., Salamon, P., Bianchi, A., Alfieri, L., Hirpa, F. A., and Feyen, L. (Aug. 2016). "Development and evaluation of a framework for global flood hazard mapping". In: *Advances in Water Resources* 94, pp. 87–102.

EC (2016). *Nomenclature of Territorial Units for Statistics*. https://ec.europa.eu/eurostat/web/nuts/background/.

Erkan, G. and Radev, D. R. (2004). "Lexrank: Graph-based lexical centrality as salience in text summarization". In: *Journal of artificial intelligence research* 22, pp. 457–479.

Halterman, A. (2017). "Mordecai: Full Text Geoparsing and Event Geocoding". In: *The Journal of Open Source Software* 2.9.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015). "Processing social media messages in mass emergency: A survey". In: *ACM Computing Surveys (CSUR)* 47.4, p. 67.

Imran, M., Castillo, C., Lucas, J., Meier, P., and Vieweg, S. (2014). "AIDR: Artificial intelligence for disaster response". In: *Proceedings of the 23rd International Conference on World Wide Web*. ACM, pp. 159–162.

Joachims, T. (1999). "Svmlight: Support vector machine". In: *SVM-Light Support Vector Machine http://svmlight.joachims.org/, University of Dortmund* 19.4.

Khare, P., Burel, G., Maynard, D., and Alani, H. (2018). "Cross-Lingual Classification of Crisis Data". en. In: *The Semantic Web – ISWC 2018*. Ed. by D. Vrandečić, K. Bontcheva, M. C. Suárez-Figueroa, V. Presutti, I. Celino, M. Sabou, L.-A. Kaffee, and E. Simperl. Vol. 11136. Cham: Springer International Publishing, pp. 617–633.

Li, H., Caragea, D., Li, X., and Caragea, C. (2018). "Comparison of Word Embeddings and Sentence Encodings as Generalized Representations for Crisis Tweet Classification Tasks". en. In: *New Zealand*, p. 13.

Liao, R. (2016). *Convolutional Text Classifier*. https://richliao.github.io/supervised/classification/2016/11/26/textclassifier-convolutional/.

Luong, T., Pham, H., and Manning, C. D. (2015). "Bilingual Word Representations with Monolingual Quality in Mind". In: *Proceedings of the 1st Workshop on Vector Space Modeling for Natural Language Processing*. Proceedings of the 1st Workshop on Vector Space Modeling for Natural Language Processing. Denver, Colorado: Association for Computational Linguistics, pp. 151–159.

Middleton, S. E., Zielinski, A., Tokarchuk, L. N., and Wang, X. (May 2013). "Social-media text mining and network analysis to support decision support for natural crisis management". In: ISCRAM 2013. In collab. with S. E. Middleton, A. Zielinski, L. N. Tokarchuk, and X. Wang.

Musaev, A., Wang, D., and Pu, C. (Sept. 2015). "LITMUS: A Multi-Service Composition System for Landslide Detection". en. In: *IEEE Transactions on Services Computing* 8.5, pp. 715–726.

Palen, L. and Anderson, K. M. (2016). "Crisis informatics—New data for extraordinary times". In: *Science* 353.6296, pp. 224–225.

Pennington, J., Socher, R., and Manning, C. (2014). "GloVe: Global vectors for word representation". In: *Proceedings of the 2014 conference on empirical methods in natural language processing (EMNLP)*, pp. 1532–1543.

Redazione ANSA (2018). *Calabria Bad weather 201810*. http://www.ansa.it/english/news/2018/10/05/mum-child-dead-as-extreme-weather-batters-south_dd387479-55cb-4249-ba69-09862501bef2.html/.

Restrepo-Estrada, C., Andrade, S. C. de, Abe, N., Fava, M. C., Mendiondo, E. M., and Albuquerque, J. P. de (Feb. 2018). "Geo-social media as a proxy for hydrometeorological data for streamflow estimation and to improve flood monitoring". en. In: *Computers & Geosciences* 111, pp. 148–158.

Schiaroli, R. (2018). *Alluvione Calabria 201810*. https://www.centrometeoitaliano.it/notizie-meteo/alluvione-calabria-2018-caduti-oltre-300-millimetri-di-pioggia-dal-2-al-5-ottobre-8-10-2018-67267/.

Severyn, A. and Moschitti, A. (2015). "Twitter sentiment analysis with deep convolutional neural networks". In: *Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval*. ACM, pp. 959–962.

UN Office for the Coordination of Humanitarian Affairs (2017). "World Humanitarian Data and Trends". In:

Vieweg, S., Castillo, C., and Imran, M. (2014). "Integrating Social Media Communications into the Rapid Assessment of Sudden Onset Disasters". en. In: *Social Informatics*. Ed. by L. M. Aiello and D. McFarland. Vol. 8851. Cham: Springer International Publishing, pp. 444–461.

Rumour Detection on Social Media for Crisis Management

Sooji Han
Department of Computer Science,
University of Sheffield,
Sheffield, S1 4DP, UK
sooji.han@sheffield.ac.uk

Fabio Ciravegna
Department of Computer Science,
University of Sheffield,
Sheffield, S1 4DP, UK
f.ciravegna@sheffield.ac.uk

ABSTRACT

We address the problem of making sense of rumour evolution during crises and emergencies. We study how understanding and capturing emerging rumours can benefit decision makers during such event. To this end, we propose a two-step framework for detecting rumours during crises. In the first step, we introduce an algorithm to identify noteworthy sub-events in real time. In the second step, we introduce a graph-based text ranking method for summarising newsworthy sub-events while events unfold. We use temporal and content-based features to achieve the effective and real-time response and management of crises situations. These features can improve efficiency in the detection of key rumours in the context of a real-world application. The effectiveness of our method is evaluated over large-scale Twitter data related to real-world crises. The results show that our framework can efficiently and effectively capture key rumours circulated during natural and human-made disasters.

Keywords

Rumours, large-scale data, event summarisation, sub-event detection, social media analysis

INTRODUCTION

Nowadays social media platforms are main sources of a variety of information with rapidly growing rates of user engagement and global mobile social media usage. According to the Global Digital Report 2018, 3.196 billion users are using social media. Along with the growth of social media, its role during emergencies and crises has become prominent (Andrews et al. 2016; Arif et al. 2017; Castillo 2016; Imran et al. 2015; Rudra et al. 2018; Zeng et al. 2016). For instance, emergency services can remotely identify areas affected by crises situations based on social media users' posts reporting what they are seeing and hearing (Yin et al. 2012) or find victims seeking help (Zubiaga et al. 2018a). Emergency responders can then make adequate decisions such as the allocation of resources and police. The enormous and continuing growth of user activities on social media is accompanied by the real-time acquisition of a substantial amount of user-generated data with an unprecedented volume and variety and different levels of veracity. As the speed of event evolution is very fast, the existence of such information in the real-time stream of social media content poses a challenge to decision makers, in particular, in time-sensitive situations such as natural disasters and terrorist attacks. It is impossible for humans to manually inspect rapidly changing and noisy messages in a timely manner. In addition, citizens can be confused by unfounded or conflicting rumours regardless of whether they were generated purposely or unintentionally.

Research areas using social media that have been in the limelight recently are *automated rumour and fake news detection* (Helmstetter and Paulheim 2018; Kwon et al. 2017; Shu et al. 2017, 2018; Wong et al. 2018) and *fact-checking* (Boididou et al. 2018; Vosoughi et al. 2017). Social media are origins of rumors and where they spread among a large number of people (Ma et al. 2018). Despite the growing interest in rumours and fake news on social media and several attempts to make sense of them in both academia and industry, the utilisation of rumours for emergency response poses several challenges (Andrews et al. 2016; Starbird et al. 2016). In this study, we aim at partially filling this gap by studying how to identify rumours appearing during crises without manually examining a large number of messages. Our framework comprises of real-time key sub-event detection and summarisation. Summaries obtained by our method can include both rumours and non-rumours. According to our experiments, most summaries contain informative details related to emergencies and reflect what draws the public's attention.

Our system can help practitioners identify not only newsworthy events but rumours to debunk or verify without examining an entire stream of messages.

In this paper, we address the problem of the early and semi-automatic identification of *rumours* on social media during crises. To this end, we first analyse rumours during emergency situations. We adopt the definition of rumour proposed by (DiFonzo and Bordia 2007): "an unverified and instrumentally relevant information statement in circulation that arises in contexts of ambiguity, danger or potential threat, and that functions to help people make sense and manage risk". We refer to (Olteanu et al. 2015) to categorise rumours by type. We claim that some information types such as 'donations and volunteer', 'caution and advice', and 'sympathy and emotional support' can contribute to situational awareness but cannot be considered as rumours. Our scope of rumour during crises include a) affected individuals, infrastructure, and utilities, b) the location of the event, c) other useful information (e.g. details about suspects and weapons). We use Twitter as a representative social media.

To help decision makers and journalists identify breaking news or understand unfolding situations as early as possible, we pose the following research question: "Which moments in event evolution are worth being paid attention to from the perspective of emergency responders?" To address the question, we introduce "noteworthy moment detection" into the framework of rumour studies. Several studies have studied bursts in the popularity of events on social media (Hu et al. 2017; Keneshloo et al. 2016; Kong et al. 2015; Matsubara et al. 2012; Wang et al. 2016). The main focus of such studies is often a 'peak'. However, a peak indicates that a rumour has already become popular (i.e. a large amount of information regarding the rumour is available). This phenomenon makes it difficult for professional analysts to take action to deal with the rumour in a timely manner. We emphasize the importance of capturing bursts of user activity along with peaks, and collectively refer to both types of events as *noteworthy moments.* The identification of such moments in rumour evolution without domain knowledge is often challenging and tricky as a boundary between noteworthy and normal moments may not be obvious to a lay person. Noteworthy sub-events are not necessarily equivalent to novelties concerning their content (i.e. topics) as considered in the area of first story detection, but they are considered to be novel in temporal context.

Having identified noteworthy sub-events, our proposed framework generates summaries of a high volume of messages. There are commonly two approaches for event summarisation. One is generating a whole new text which contains important information. The other is extracting representative messages that have high scores. In this work, we choose the latter approach. Several studies on crisis management via social media have proposed sub-event summarisation methods (Kedzie et al. 2015; Nguyen et al. 2015; Rudra et al. 2015, 2016, 2018). The state-of-the-art work on event summarisation usually focuses on achieving higher Recall-Oriented Understudy for Gisting Evaluation (ROUGE) scores (Lin 2004). ROUGE is a metric which evaluates the quality of a summary by comparing overlapping n-grams between the summary and gold standard references. Our framework also consists of two steps: noteworthy moment detection and sub-event summarisation. What differentiates our study from the state-of-the-art work is that we undertake an extensive analysis of rumours that emerge and evolve during crises. We believe that understanding rumour evolution during crises can benefit both the improvement of situational awareness during crises and diverse realms of rumour studies. Attempts to understand differences between true information and false rumours have been extensively studied in the community of rumour studies. Crisis management via social media can benefit from findings of rumour studies. Meanwhile, examples of crises and emergencies can be useful resources for rumour studies.

The main contributions of our work are summarised as follows:

1. We propose a semi-automatic framework for the early detection and summarisation of key sub-events. Our framework can identify potential rumours that draw people's attention before their popularity reaches a peak. Our framework makes it possible for decision makers to understand developing situations quickly and to take action proactively. This can lead to the minimization of the extent of the damage.
2. We demonstrate that our framework can work with events with different types of language and different sizes. We conduct experiments over real-world datasets that mainly consist of English, Italian and Russian tweets.
3. We evaluate our framework's effectiveness quantitatively and qualitatively by comparing different methods for key sub-event detection.
4. Our framework generates readable and meaningful summaries that cover a wide range of information so that end users who do not have background knowledge on models can easily understand unfolding events.

REQUIREMENTS AND SYSTEM DESIGN

- **Early detection**: A system must be able to capture informative reports in the early stages of event evolution. This makes it possible for decision makers to be prepared for potential hazards in the near future.

- **Real-time detection**: The speed of the dissemination of information during crisis is very fast. A system must be able to process a stream of posts in real time so that decision makers can plan urgent and planned remedial actions in a timely manner.
- **Scalability**: Rumours during crises and emergencies are usually unexpected, sudden, and unusual. One major drawback of using a threshold to identify key moments such as emerging patterns and spikes in event evolution is that system performance is highly dependent on data sizes.
- **Generalisation**: A system must be transferrable to events from different domains and with different characteristics (e.g., language, burstiness, and geolocation).

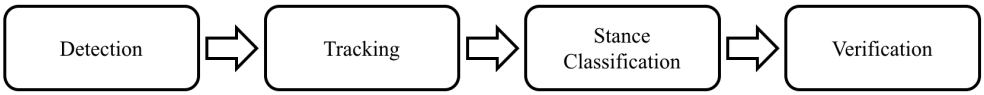


Figure 1. Architecture for rumour studies.

Figure 1 shows a commonly used architecture in rumour studies (Zubiaga et al. 2018b). Systems for rumour detection perform binary classification to decide whether a piece of information (e.g. a single tweet) is a rumour or non-rumour. In general, tweets during crises can be collected using a set of keywords related to an event or geolocation. For example, relevant keywords such as 'bostonexplosion', 'bostonbombing', 'bostonblast', and 'prayforboston' can be identified at the early stage of the Boston marathon bombings. In particular, the hashtag starting with 'prayfor' is very popular worldwide and usually appears when tragic events take place. Due to this data collection procedure, there can be lots of irrelevant or uninformative posts in a stream. Therefore, we argue that it is impractical to apply a rumour detection system to a raw stream of posts. Our framework will bridge the gap between real-time data collection and the automatic detection of breaking news and rumours.

We further discuss why 'peaks' are not appropriate signals for key moments detection. Let us think about the task of determining whether the time window marked in square in Figure 2a is noteworthy or not. This task may become less challenging if we observe the next time window. For example, we can confirm that the time window marked in square is a key moment without doubt in Figure 2b because it is a 'peak'. On the other hand, it is still challenging to decide whether the target window is noteworthy or not in Figure 2c. The target lies on the increasing line of the graph. However, the amount of increase is not significant compared to that between the time windows marked in square and star. By looking at this simple example, we can draw two conclusions. Firstly, it is impossible to identify a peak without observing future instances. This means the detection of peaks in event evolution cannot be done in real time. This is why several studies on key moment detection employ retrospective approaches for detecting peaks. Secondly, the term 'noteworthy moment' can be considered an anomaly of interest to analysts or domain experts. As several studies on anomaly analysis point out, it is subjective to judge whether a point in the evolution of an event can be considered to be noteworthy or not (Aggarwal 2015). The distinction between noteworthy and non-noteworthy moments could be regulated based on the interest of analysts.

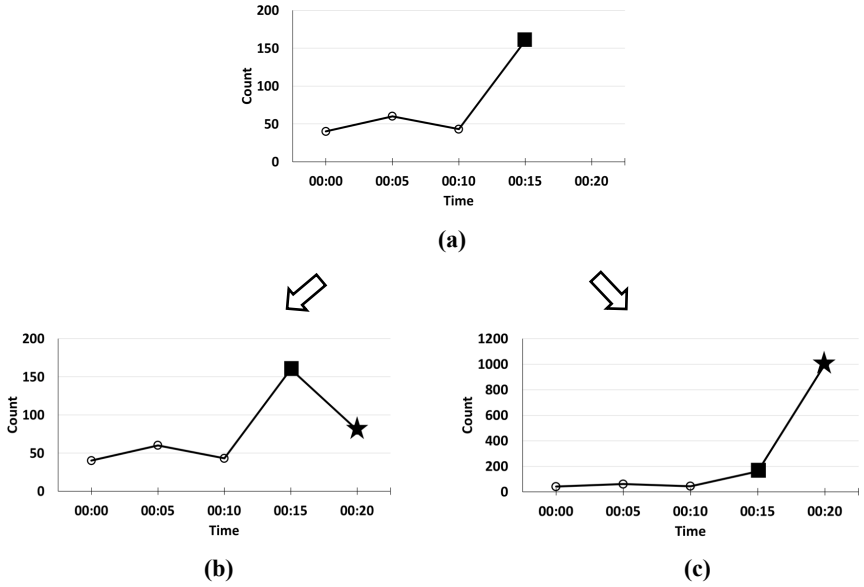


Figure 2. Examples of event evolution.

Previous studies on key sub-event detection utilize thresholds. Specifically, their methods recognize sub-events the volume of messages of which exceeds a certain threshold. A drawback of most existing methods based on thresholds is that they tend to capture a large number of instances in periods of persistent decline. However, we observe that these instances are generally spurious anomalies in the context of content novelty. We are interested in detecting newly emerging or developing stories rather than already seen sub-events with a high volume of messages. Our observation shows that the same topic can be actively discussed even after its popularity reaches a peak for several reasons such as the time difference between locations of users. Instances located in a persistently falling line are not of interest because they are likely to be duplicates of key sub-events in the past. We will further investigate this argument using real-world datasets. We design our architecture for *event-level* studies of crises in the real world. We aim to aid tweet-level rumour studies by reducing data granularity. We propose our method as a pre-processing step for rumour detection in crises and emergencies. The output of our framework can be used as *candidates* for the construction of annotated data for rumour detection. The state-of-the-art work on rumour detection annotated only highly retweeted tweets (Ma et al. 2017; Zubiaga et al. 2016b; a). This data sampling may lead to biased results for rumour detection as some minor but important sub-events do not get a high number of reactions (Meladianos et al. 2015). The fine-grained detection, tracking, stance classification, and verification of rumours are beyond the scope of this paper.

NOTEWORTHY MOMENT DETECTION

We propose a rule-based algorithm for detecting noteworthy moments in quasi real-time. Our method identifies key moments by solely using the left-hand side of any instances (i.e. time window) of a time series. Table 1 describes features associated with the number of tweets. We use the Boston marathon bombings to empirically choose our parameters. Specifically, we visualise key moments detected using different combinations of parameter values and select a set of parameters which satisfies best our hypothesis: noteworthy moments lie in increasing lines in even evolution graphs. We set α for EWM_MEAN to 0.3, S for DIFF_RMEAN to 3, and λ for ψ to 0.01. Recall that it is subjective to judge whether a point in the evolution of an event can be considered to be noteworthy or not. Therefore, the used parameter values are rules of thumb. Even so, our experiments show that they are scalable and generalize well to datasets with different sizes and from different types of crises.

Table 1. Features extracted from the tweets within the i^{th} time window.

Name	Description	Mathematical Equation
COUNT	The number of tweets	c_i
EWM_MEAN	Exponentially weighted average of COUNT	$s_i = \begin{cases} c_i & i = 1 \\ (1-\alpha) * s_{i-1} + \alpha * c_i & i = 2, \dots, N \end{cases}$, where $0 < \alpha \leq 1$
DIFF	Difference between s_i and s_{i-1}	$d_i = \begin{cases} 0 & i = 1 \\ s_i - s_{i-1} & i = 2, \dots, N \end{cases}$
DIFF_RMEAN	Rolling mean of d with a window size of S	$z_i = \begin{cases} 0 & i = 1 \\ \frac{\sum_{k=1}^{\min\{S, i-1\}} d_{i-k}}{\min\{S, i-1\}} & i = 2, \dots, N \end{cases}$
STDEV	Sample standard deviation of 4 time windows	$std_i = \begin{cases} 0 & i = 1 \\ \sqrt{\frac{\sum_{k=0}^{\min\{3, i-1\}} (s_{i-k} - \bar{s})^2}{\min\{i, 4\} - 1}} & i = 2, \dots, N \end{cases}$, where $\bar{s}$ is the mean of s_i.
θ	A combination of EWM_MEAN and STDEV	$\theta_i = \begin{cases} 0 & i = 1 \\ s_{i-1} + std_i & i = 2, \dots, N \end{cases}$
ψ	A combination of DIFF and DIFF_RMEAN	$\psi_i = \begin{cases} 0 & i = 1 \\ \lambda * z_{i-1} + (1-\lambda) * d_i & i = 2, \dots, N \end{cases}$

We formulate noteworthy sub-event detection into a binary classification task. Algorithm 1 describes the rule-based procedure of identifying noteworthy moments using the above features. In order to simulate a real-time scenario, we assume that a time series consists of N time windows. Given the N instances with the features, the algorithm assigns binary labels to time windows based on a set of conditions. A label is 1 if a window is noteworthy and is 0 otherwise. Some existing studies define thresholds for the absolute number of messages of each time window (Gillani et al. 2017; Shamma et al. 2009; Zubiaga et al. 2012). Others define thresholds for differences in the number of messages over several time windows (Nichols et al. 2012; Peng et al. 2018). Our algorithm overcomes several limitations that existing methods for key sub-event detection have. Firstly, results of the state-of-the-art approaches for sub-event detection are highly dependent on the total number of tweets posted during event evolution. This poses a challenge because the performance of a detection method can be poor if an inappropriate threshold is chosen. To overcome this, we adjust thresholds in the early stages of event evolution (LINE 3-7). As rules of thumb, we set H to 24 for instantaneous events and to 36 for progressive events. In other words, for instantaneous events, thresholds are adjusted during the first 24 time windows regardless of resampling window size. Using a larger value of H indicates our algorithm needs a longer time to learn event evolution. In general, it takes longer to draw people's attention in the case of progressive events as interesting sub-events develop slower than they do in instantaneous events. Secondly, our algorithm considers both the absolute volume (LINE 10-14) and differences in the number of messages (LINE 15-17) to detect noteworthy sub-events. Consequently, detected sub-events have a significant number of messages to be considered anomalous. Data instances lying in decreasing lines in time series plots are filtered out. We implement our method via Python.

Algorithm 1. Algorithm for the real-time and automatic detection of noteworthy moments.

Algorithm 1. Noteworthy sub-event detection

Input: N time series with features
Output: Binary labels

```
1: for i=1 to N do  // Iterate N time windows
2:     // Calculate thresholds
3:     H = constant
4:     while i < H do
5:         AVG = mean(COUNT)  // the mean of COUNT up to the i^th time window
6:         THRESHOLD = min(AVG, 100)
7:         DIFF_THRESHOLD = max(θ)  // the maximum θ up to the i^th time window
8:     if i == 0 then  LABEL ← 0
9:     else
10:        if (COUNT > THRESHOLD) and (COUNT >10) then
11:            if PREVIOUS LABEL == 1 then
12:                if EWM_MEAN ≥ θ then  LABEL ← 1
13:                elif PREVIOUS COUNT ≤ COUNT then  LABEL ← 1
14:                else  LABEL ← 0
15:            elif (PREVIOUS LABEL == 0) and (EWM_MEAN > θ) then
16:                if ψ > DIFF_THRESHOLD then  LABEL ← 1
17:                else  LABEL ← 0
18:            else  LABEL ← 0
19:        else  LABEL ← 0
```

EVENT SUMMARISATION

Given detected noteworthy moments, we extract representative tweets that can summarise unfolding events within each key moment. One simple approach to extract summaries are to assign scores to words in each tweet using a frequency or term frequency-inverse document frequency. However, this approach generally produces poor results. We use an unsupervised graph-based ranking algorithm for text called TextRank (Mihalcea and Tarau 2004). We decide to use TextRank for two reasons. One reason is that it is fully unsupervised. The performance of supervised text ranking models is highly dependent on training data. On the other hand, it is capable of extracting summaries solely based on the text itself. This is particularly important for crises as they are usually unseen and evolve unexpectedly. Another reason is that TextRank can be adapted to short text, which is suitable for tweets. We implement the TextRank using an open source software in Python (Barrios et al. 2016). However, the representation of the graphs of words in their implementation favours long tweets. To avoid this limitation, we follow the representation proposed by (Meladianos et al. 2015). Let a 'document' refer to a set of tweets

published within a time window. Given a document, we firstly generate a graph G whose vertices (V) are words and edges (E) are co-occurrence relation. If two words w_i and w_j co-occur in a tweet, an edge between two vertices V_i and V_j is created. Next, a weight $w_{ij} = \frac{1}{p-1}$ is added to the edge, where p is the number of unique terms in the tweet. If vertices already exist in a graph, the edge weight is accumulated. By repeating this procedure for the document, the algorithm returns scores for words in the document. Given the word scores, the method calculates scores for each tweet in the document by adding up the scores of words appearing in each tweet. Finally, we sort tweets in reverse order and use the top-K tweets as extractive summaries of each key sub-event. We use 10 for K in our experiments. Using a higher number for K may help users discover more sub-events. However, it is not viable for humans to read and annotate all available tweets due to the large volume of tweets during breaking events and time constraints (Zubiaga et al. 2016b; a).

EXPERIMENTS

Datasets

We use two publicly available datasets. A summary is shown in Table 2.

Twitter Event 2012-2016 (Zubiaga 2018) : This data consists of over 147 million tweets about 30 real-world events that took place between 2012 and 2016. The tweets were collected using Twitter's streaming API with keywords and hashtags related to each event. We select three human-made crises: Boston marathon bombings (2013), Ferguson unrest (2014), and Sydney siege (2014). We refer to this data as 'Event1216' hereinafter.

CrisisLexT26 (Olteanu et al. 2014): This data includes tweets regarding 26 hazardous events that unfolded between 2012 and 2013. It is designed to enable decision makers and citizens to understand unfolding disaster situations and obtain information of interest from social media. We select two natural disasters: Northern Italy earthquakes (2012) and Russian meteor (2013). The data size is small, but we decide to use this to show the scalability and generalization of our framework. We refer to this data as 'CrisisLex' hereinafter.

In Table 2, we define the development type of the Ferguson unrest as 'Mixed'. The initial shooting was instantaneous, but the developments were progressive. Table 3 shows the keywords used by the authors of the datasets when retrieving tweets. Some keywords such as 'ferguson' are too general. It is time-consuming to examine the entire set of collected messages as it contains a large number of non-rumours. Therefore, we can appreciate the importance of the detection of noteworthy moments in studying rumours during crises and emergencies. We carry out *event-level* analysis of tweets posted during crises in the real world. Specifically, we are interested in discovering what stories attract the public's attention and candidates for rumours to be debunked and verified by human experts while events unfold. There exists a trade-off between identifying key sub-events in real-time and manually examining candidates for key sub-events. It is not viable to identify key sub-events for every second as large-scale and noisy messages are generated at a rapid pace in social media (Atefeh and Khreich 2015). To tackle the trade-off, we employ a sliding window as previous studies on sub-event detection proposed. We use a 1-minute window for the Boston marathon bombings and a 5-minute window for the others. We use different window sizes for two reasons. One is to show that our method is versatile as it can work for different window sizes. The other is to embody different characteristics of event evolution. For example, sub-events such as affected individuals and details regarding suspects change very rapidly and situations tend to be chaotic and dynamic during the Boston marathon bombings. It is crucial to minimise delays in key sub-event detection by using a shorter window. During the Sydney siege, situations are less likely to require instant emergency responses as a gunman was holding hostages at a café for several hours. It is reasonable to use a longer window.

Table 2. Description of datasets.

Dataset	Event	Year	Country	Start	End	Domain	Development	Tweet Count
Event1216	Boston marathon bombings	2013	US	Apr 15	Apr 15	Bombings	Instantaneous	1,753,836
	Ferguson unrest	2014	US	Aug 9	Aug 25	Shooting/Riots	Mixed	4,183,421
	Sydney siege	2014	US	Dec 14	Dec 17	Hostage taking	Instantaneous	1,292,948
CrisisLex	Northern Italy earthquakes	2012	Italy	May 18	May 31	Earthquake	Instantaneous	4,231
	Russian meteor	2013	Russia	Feb 14	Feb 15	Meteorite	Instantaneous	4,498

Table 3. Keywords used to collect tweets (Olteanu et al. 2014; Zubiaga 2018)

Dataset	Event	Keywords
Event1216	Boston marathon bombings	boston, marathon, #prayforboston
	Ferguson unrest	ferguson
	Sydney siege	#sydneysiege, sydney, gunman, lindt, martin place
CrisisLex	Northern Italy earthquakes	earthquake italy, quake italy, #modena, #sanfelice, San Felice, modena terremoto, #terremoto, #norditalia, modena earthquake, modena quake, terremoto italia
	Russian meteor	#RussianMeteor, #Chelyabinsk, #челябинск, #метеорит, #meteor, #meteorite, russia meteor, russian meteor

Baselines

We compare our method with two baselines which exploit thresholds to identify key sub-events. We reproduce the baselines via Python.

Moving-threshold burst detection (Hsieh et al. 2012): Given the resampled time series, it computes the mean μ and standard deviation σ of the number of tweets observed up to the current time t_i. Then, the threshold at the t_i is defined by $\alpha * (\mu + \beta * \sigma)$. The parameters α and β are set between 0.7 and 1.0, and between 1.5 and 2.0, respectively. However, the authors did not specify default values for their parameters. If the number of tweets at t_i is greater than the threshold, the method annotates the instance at t_i as a key moment.

Outlier-based sub-event detection (Zubiaga et al. 2012): Given the resampled time series, it identifies the instance at t_i as an event of interest if the tweeting rate at t_i is higher than 90% of previously seen tweeting rates.

RESULTS AND EVALUATION

Quantitative Evaluation

Table 4. The results of noteworthy moment detection.

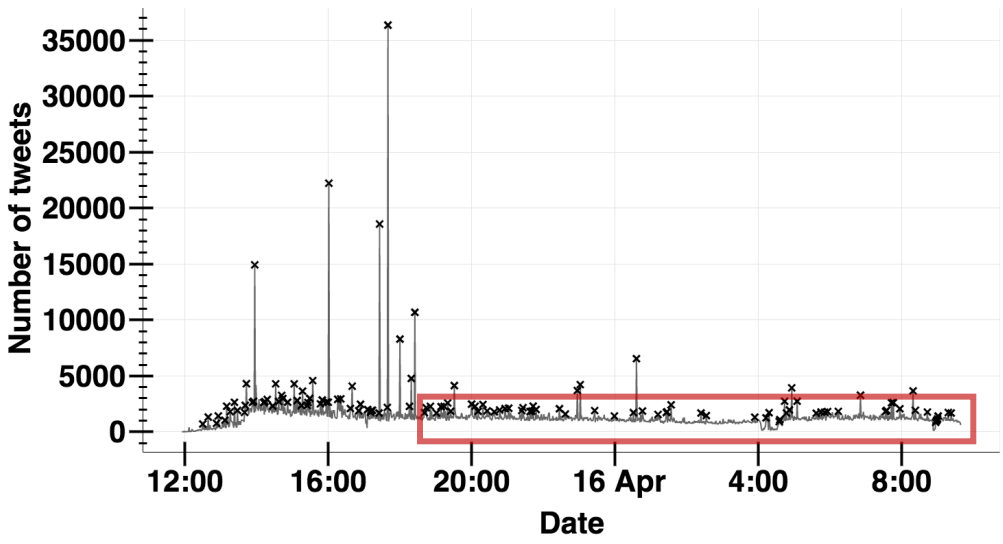
		Our method		Zubiaga		Hsieh	
Event	**# of windows**	**# of key moments**	**% of key moments**	**# of key moments**	**% of key moments**	**# of key moments**	**% of key moments**
Boston bombings	1,305	125	9.6	1,299	99.5	40 - 95	3.1 – 7.3
Ferguson unrest	4,651	603	13.0	4,093	88.0	341 - 646	7.3 – 13.9
Sydney siege	708	11	1.6	688	97.2	13 - 42	1.8 – 5.9
Italy earthquakes	3,585	40	1.1	13	0.4	126 -180	3.5 – 5.0
Russian meteor	337	29	8.6	191	56.7	20 - 50	5.9 – 14.8

Table 4 compares the number and percentage of detected noteworthy moments. (Hsieh et al. 2012) can detect different numbers of sub-events by adjusting parameters. The authors did not propose default values for their parameters. For a fair comparison, we randomly and uniformly draw parameter values from the ranges proposed in the original work. We perform the random sampling 100 times for each event. In Table 4, we show the minimum and maximum number of detected key moments. We find that the higher α and β are, the smaller number of windows are detected. For our method, we set H in Algorithm 1 to 36 the Ferguson unrest and to 24 for the others. We find that the number of detected sub-events depends not only on the total number of tweets but on burstiness. For example, the Sydney siege exhibits huge bursts (i.e. spikes) separated by long periods of inactivity. Small fluctuations between large spikes tend to be considered less noteworthy. On the other hand, the evolution of the Boston marathon bombings displays more bursty behaviour, and therefore relatively small bursts are identified as noteworthy moments. As can be seen in Table 4, Zubiaga's method performs poorly. In particular, their method cannot generalise to datasets with different characteristics. It identifies most of the time windows as key moments for the Event1216. It is not beneficial to perform sub-event detection if an algorithm recognises most time windows as key sub-events. In addition, previous study on sub-detection also showed that Zubiaga's method detect a large number of spurious outliers (Meladianos et al. 2015). On the contrary, it captures about 0.4% of the

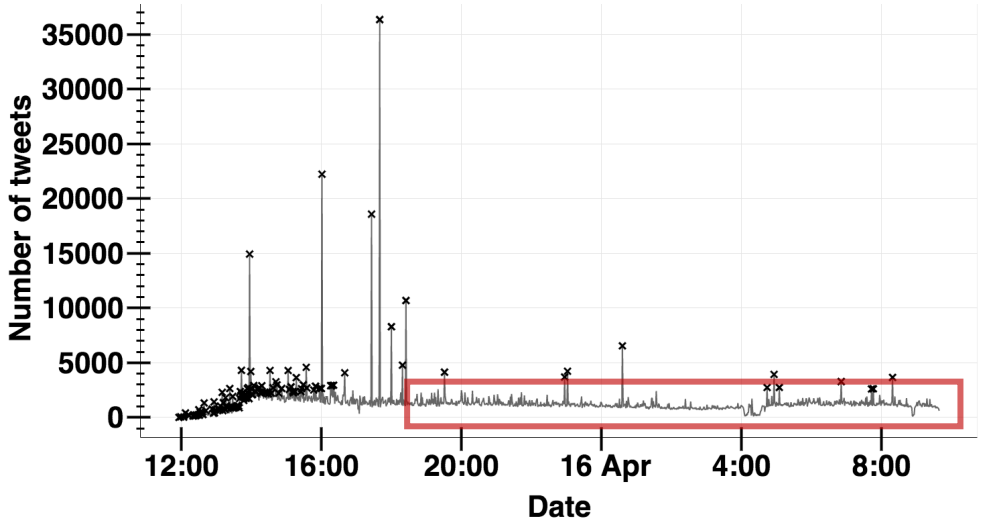
time windows for the Northern Italy earthquakes. Hsieh's method detects a reasonable number of windows. Therefore, we further compare the results in the qualitative evaluation.

Qualitative Evaluation

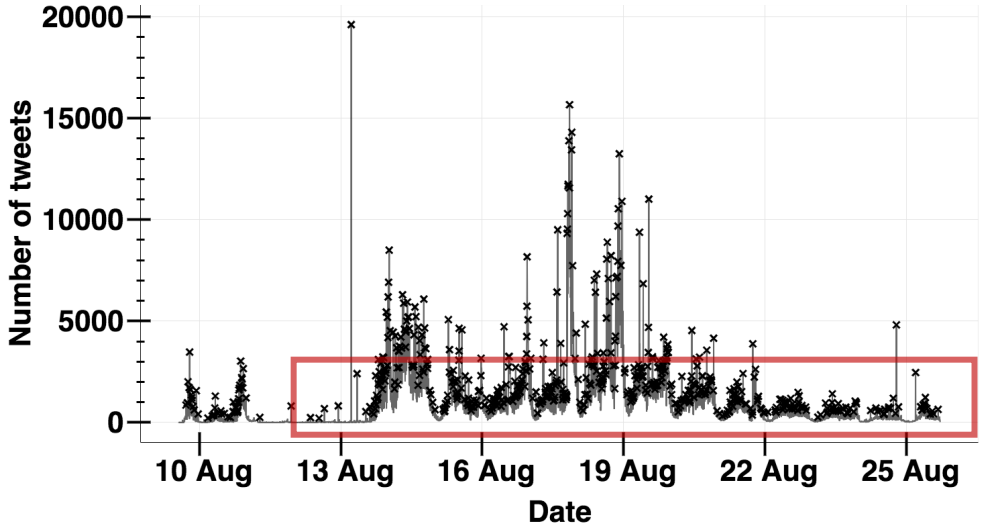
Not only the number of tweets but the distribution of key moments does matter. Here we compare the results obtained by our method and Hsieh's method. The major limitation of their method is their threshold is not adaptive to abrupt and extreme changes in event evolution. Recall that their threshold is based on the mean and standard deviation of the number of messages of preceding time windows. If there exist time windows the volume of messages of which is high in the past, their threshold tends to stay high afterwards. The evolution patterns of events on social media exhibit bursts of intense activity separated by long periods of inactivity or low-frequency periods (Barabási 2005). Taken all together, their method becomes less capable of detecting key sub-events with the relatively low number of messages as an event unfolds. We explain this phenomenon in detail with two real-world examples. Figure 3a and 3b show detected key sub-events for the Boston marathon bombings. For a fair comparison, we experimented with Hsieh's parameters outside the proposed ranges so that the number of sub-events detected by our method is similar to that detected by their method. Figure 3a shows detected key moments when $\alpha = 0.661$ and $\beta = 1.45$. One observation we can make is the results obtained by our method more evenly spread across the entire event evolution than those obtained by their method does. This means that our method is capable of detecting key moments in various phases of event evolution. Hsieh's method tends to detect more instances in the early stages of event evolution than our method does. However, their method only identifies spikes after 16:15 on 15 April. As we have already addressed previously, focusing on peaks in event evolution can prohibit the early detection of rumours. Figure 3c and 3d show detected key moments for the Ferguson unrest. It is clearly shown that a large number of instances are not detected in the red box in Figure 3d. This indicates that our method is better at early detection than Hsieh's method is. Figure 4a and 4b illustrate this observation more clearly. Hsieh's method detects not only instances on increasing lines but also those on decreasing lines. Figure 5 shows a part of Figure 3d. We can observe that all time windows, the number of messages of which is above a certain value are detected as key sub-events. We further investigate why these data examples are likely to be false anomalies in the following section.



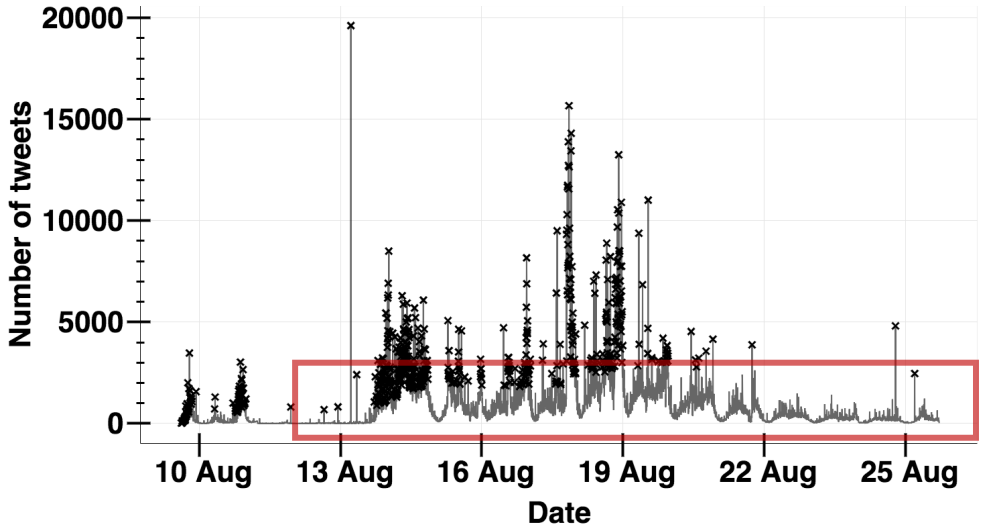
(a) 125 time windows are detected via our method.



(b) 129 time windows are detected via Hsieh's method



(c) 603 time windows are detected via our method



(d) 599 time windows are detected via Hsieh et al.'s method

Figure 3. Visual comparison of the results obtained by our method (a, c) and Hsieh's method (b, d). Detected key moments are marked with ×. (a) and (b) show the Boston marathon bombings. (c) and (d) show the Ferguson unrest.

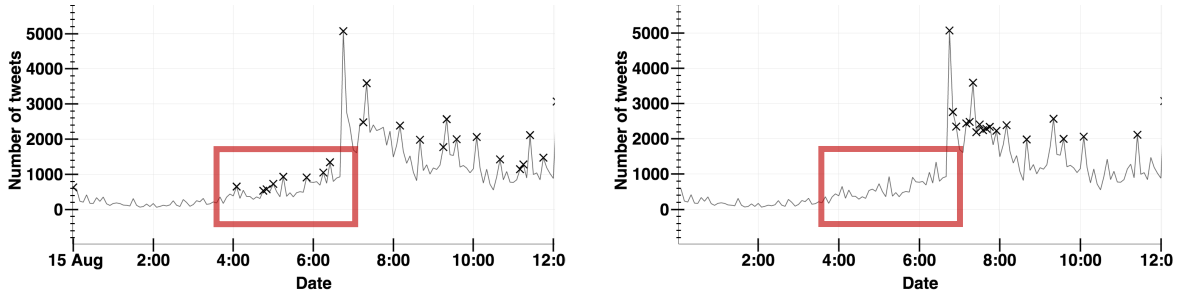


Figure 4. Partial plots of the Ferguson unrest. Detected noteworthy moments are marked with ×. (a) the results of our method (b) the results of Hsieh's method

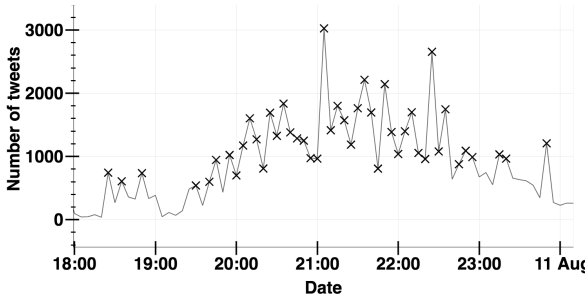


Figure 5. An example showing that Hsieh's method detects both increasing and fading patterns in event evolution.

Rumours During Crises

We apply the event summarisation method to the detected noteworthy moments. We then manually investigate the top 10 representative tweets of each key sub-event. Here, we show some examples of rumours appeared in the noteworthy moments detected by our method and their types. Note that there are more than 10 rumours as the given examples are found across an entire event rather than from one specific key moment. Rumours are classified into four categories: a) affected individuals, infrastructure, and utilities, b) the location of an event, c) other useful information (e.g. details about suspects and weapons). We present some rumours found in the detected noteworthy moments for two different datasets. As can be seen in the following tables, several informative and useful sub-events can be captured by focusing on noteworthy moments rather than the whole sequence. We find that several rumours spread during the Boston marathon bombings and Sydney siege. In particular, several posts related to a certain sub-event but with different entities (e.g. numbers) circulated. For the Boston marathon bombings, for instance, people reported different numbers and locations of explosive devices and whether a victim is an 8-year-old boy or girl. For the Sydney siege, different numbers of hostages and injured people were reported. There were also lots of details related to suspects.

- Boston marathon bombings

Type	Rumour	Type	Rumour
b	Two explosions near finish line	a	8-year-old girl or boy?
b	The 1st explosion reported on Boylston Street	a	An 8-year old girl is not one of the victims, an 8-year-old boy is dead
c	2 explosive devices are found	a	An 8-year-old girl died while running for her best friend
c	2 more explosive devices are found	a	An 8-year old girl/boy died while running for the Sandy Hook kids
c	Boston bombings are a "False Flag" operation	a	An 8-year-old boy killed has been identified as Martin Richard
a	8-year-old child died	a	The killed boy was waiting for his dad to finish his marathon
a	8-year-old boy/girl died	a	Mom and sister of the 8-year-old boy who was killed are injured
a	8-year-old girl died	b	The third explosion at the JFK library (unknown connection)
c	4 explosive devices	c	A fire broke out at the JFK library. Not an explosion
c	No one is in custody	c	Pressure cooker bombs were placed in black duffel bags
c	The third explosion has been reported	c	The third device is found

- Sydney siege

Type	Rumour	Type	Rumour
b, c	A gunman is taking hostages at a café in Martin Place.	c	The hostage taker is named as Man Haron Monis
b, c	An ISIS flag is being displayed on the window of a café	c	Man Haron Monis fled from Iran to Australia in 1996
a	2 killed and 3 seriously injured	a	6 more escaped and 11 in total have escaped
c	Hostages are being forced to hold an ISIS flag	c	Gunman is reportedly killed
b, c	Two gunmen inside the café under siege	a	2 dead (no information regarding the gunman's death)
a	Up to 20 hostages are being held	a, c	3 dead including the gunman (2 hostages and gunman dead)
a, b	Opera house has been evacuated	c	Prime Minister Abbott says Man Monis held a gun license
c	Sydney airspace closed	c	Shots fired
c	Gunman wants to talk to the Prime Minister	a, c	An Islamic extremist took 17 people hostages today
c	5 possible bombs in the city	c	Gunman wants ISIS flags
a	40-50 hostages being held	c	The gunman is carrying 2 bombs
b, c	Gunman says he has 4 bombs/devices around Sydney.	a	2 more hostages escape, 5 now have escaped.
a, c	2 dead including the gunman	c	The gunman is a lone wolf/self-styled.
c	Man Haron Monis is an Iranian cleric on bail for 40 sexual offences and accessory to the murder of his ex-wife.	a	Tori Johnson was the Lindt Cafe manager and tried to take the gun away from the man
a	Hostages who died are named as Tori Johnson, 34 & Katrina Dawson, 38	c	The flag at the window of the café is not an ISIS flag.

A hypothesis of our study is that newsworthy stories and rumours can be detected from time windows lying in increasing lines in even evolution graphs. We further study when rumours are detected for the first time using summaries obtained via our framework. The experimental results confirm our hypothesis. Table 5 shows whether some key rumours appear in noteworthy moments (i.e. increasing lines and peaks) or decaying lines for the first time. Most of the key rumours are detected at noteworthy moments, and therefore, we prove that our hypothesis is acceptable.

Table 5. Table shows whether key rumours detected from our summaries appear in noteworthy moments or time windows lying in decreasing lines in event evolution.

Timestamp	Rumour	Time window type
11:59 Apr 15	Two explosions near finish line	Noteworthy
12:24 Apr 15	The 1st explosion reported on Boylston Street	Decaying
13:28 Apr 15	Boston bombings are a “False Flag" operation	Noteworthy
22:24 Apr 15	An 8-year-old boy killed has been identified as Martin Richard	Noteworthy
19:49 Apr 15	The killed boy was waiting for his dad to finish his marathon.	Noteworthy
12:44 Apr 15	The third device has been found.	Noteworthy
12:42 Apr 15	Police tell people to stay away from the JFK library	Noteworthy
14:27 Apr 15	A fire broke out at the JFK library. Not an explosion.	Noteworthy
14:12 Apr 15	A 20-year-old Saudi Arabian man is in custody.	Noteworthy
09:03 Apr 16	Bombs are made from pressure cookers.	Noteworthy
09:23 Apr 16	Pressure cooker bombs were placed in black duffel bags.	Noteworthy

CONCLUSION AND FUTURE RESEARCH

In this paper, we have proposed a two-step framework to aid rumour detection during crises in real time. There have been several attempts to verify rumours in various domains in the community of rumour studies. However, rumours during crises are new, and therefore there is no *evidence* to debunk or verify claims when crises are unfolding. It is very challenging to develop an automatic system which is capable of verifying such rumours. Rumour detection during crises, however, can be automated and provide useful information for managers and the public. Therefore, our research aims at helping emergency responders and citizens detect emerging and developing rumours without examining an enormous number of messages. The first part of our framework detects *noteworthy moments* that draw the public’s attention during crises. We view noteworthy moments or key sub-events as outliers of interest to decision makers and other stakeholders. The performance of sub-event detection methods based on

thresholds is highly dependent on characteristics of data such as the total number of tweets and burstiness. To overcome this limitation, we incorporate several rules which take into account the absolute volume of messages and differences in the number of messages. Our rule-based sub-event detection system can be adaptive to abrupt and extreme changes in event evolution on social media. Our system can work in real time. This will enable decision makers to plan appropriate actions as early as possible. The second part extracts summaries that represent detected key moments. We employ an unsupervised graph-based text ranking algorithm called TextRank to assign scores to messages. We conducted experiments over large-scale and real-world crises datasets. We show the generalization and scalability of our method by using the datasets with different languages and characteristics such as bursty patterns and the total number of messages. The experimental results show that our method can perform the early detection of informative reports and rumours spreading during different types of crises in a real-time scenario. A common role of social media in crisis management is to improve situational awareness by analysing early reports of events. We have found that there exist several rumours during crises and their contents evolve over time. This behaviour of rumours has been extensively studied in the community of rumour studies. The application of different realms of rumour studies such as rumour tracking and stance classification can benefit emergency responders in real time. For example, decision makers will be able to distinguish rumours that are likely to be false from facts in the initial stages of rumour evolution. They can then take action to debunk and verify rumours in a timely manner. This can lead to the minimization of disaster-related losses. In conclusion, this paper aims to benefit emergency management by mining rumours evolving during crises. We have shown what rumours evolve during crises. Our experiments with real-world examples show that key rumours and informative reports can be detected from *noteworthy moments*. Our research can bridge the gap between the state-of-the-art work on rumours on social media and real-world needs for crisis management.

Future research will delve into how to fully automate rumour detection during crises. Our current system is semi-automatic. It produces summaries of detected noteworthy sub-events. However, these summaries can include rumours and non-rumours. Humans still need to judge whether each summary tweet is a rumour or non-rumour. We will further investigate characteristics of rumours during crises so that a system can distinguish rumours from non-rumours without a manual inspection.

ACKNOWLEDGEMENT

We thank Vitaveska Lanfranchi for helpful comments and discussions on an early draft of this paper. This project was partially funded by the European Commission as part of the Seta European Project (contract no. 688082), Horizon 2020 framework.

REFERENCES

Aggarwal, C. C. (2015). "Outlier Analysis." *Data Mining: The Textbook*, C. C. Aggarwal, ed., Springer International Publishing, Cham, 237–263.

Andrews, C. A., Fichet, E. S., Ding, Y., Spiro, E. S., and Starbird, K. (2016). "Keeping Up with the Tweet-dashians: The Impact of `Official- Accounts on Online Rumoring." *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing - CSCW '16*, ACM Press, San Francisco, California, USA, 451–464.

Arif, A., Robinson, J. J., Stanek, S. A., Fichet, E. S., Townsend, P., Worku, Z., and Starbird, K. (2017). "A Closer Look at the Self-Correcting Crowd: Examining Corrections in Online Rumors." *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, CSCW '17, ACM, New York, NY, USA, 155–168.

Atefeh, F., and Khreich, W. (2015). "A Survey of Techniques for Event Detection in Twitter." *Computational Intelligence*, 31(1), 132–164.

Barabási, A.-L. (2005). "The origin of bursts and heavy tails in human dynamics." *Nature*, 435(7039), 207–211.

Barrios, F., López, F., Argerich, L., and Wachenchauzer, R. (2016). "Variations of the Similarity Function of TextRank for Automated Summarization." *arXiv:1602.03606 [cs]*.

Boididou, C., Middleton, S. E., Jin, Z., Papadopoulos, S., Dang-Nguyen, D.-T., Boato, G., and Kompatsiaris, Y. (2018). "Verifying information with multimedia content on twitter." *Multimedia Tools and Applications*, 77(12), 15545–15571.

Castillo, C. (2016). *Big Crisis Data: Social Media in Disasters and Time-Critical Situations*. Cambridge University Press.

DiFonzo, N., and Bordia, P. (2007). *Rumor psychology: social and organizational approaches*. American Psychological Association, Washington, DC.

Gillani, M., Ilyas, M. U., Saleh, S., Alowibdi, J. S., Aljohani, N., and Alotaibi, F. S. (2017). "Post Summarization of Microblogs of Sporting Events." *Proceedings of the 26th International Conference on World Wide*

Web Companion - WWW '17 Companion, ACM Press, Perth, Australia, 59–68.

Helmstetter, S., and Paulheim, H. (2018). "Weakly Supervised Learning for Fake News Detection on Twitter." *2018 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM)*, 274–277.

Hsieh, L. C., Lee, C. W., Chiu, T. H., and Hsu, W. (2012). "Live Semantic Sport Highlight Detection Based on Analyzing Tweets of Twitter." *2012 IEEE International Conference on Multimedia and Expo*, 949–954.

Hu, Y., Hu, C., Fu, S., Fang, M., and Xu, W. (2017). "Predicting Key Events in the Popularity Evolution of Online Information." *PLOS ONE*, (W.-B. Du, ed.), 12(1), e0168749.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015). "Processing Social Media Messages in Mass Emergency: A Survey." *ACM Comput. Surv.*, 47(4), 67:1–67:38.

Kedzie, C., McKeown, K., and Diaz, F. (2015). "Predicting Salient Updates for Disaster Summarization." *Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing (Volume 1: Long Papers)*, Association for Computational Linguistics, Beijing, China, 1608–1617.

Kong, S., Ye, F., Feng, L., and Zhao, Z. (2015). "Towards the prediction problems of bursting hashtags on Twitter." *Journal of the Association for Information Science and Technology*, 66(12), 2566–2579.

Kwon, S., Cha, M., and Jung, K. (2017). "Rumor Detection over Varying Time Windows." *PLOS ONE*, 12(1), 1–19.

Ma, J., Gao, W., and Wong, K.-F. (2017). "Detect Rumors in Microblog Posts Using Propagation Structure via Kernel Learning." *Proceedings of the 55th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, Association for Computational Linguistics, Vancouver, Canada, 708–717.

Matsubara, Y., Sakurai, Y., Prakash, B. A., Li, L., and Faloutsos, C. (2012). "Rise and Fall Patterns of Information Diffusion: Model and Implications." *Proceedings of the 18th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, KDD '12, ACM, New York, NY, USA, 6–14.

Meladianos, P., Nikolentzos, G., Rousseau, F., Stavrakas, Y., and Vazirgiannis, M. (2015). "Degeneracy-Based Real-Time Sub-Event Detection in Twitter Stream." *undefined*, </paper/Degeneracy-Based-Real-Time-Sub-Event-Detection-in-Meladianos-Nikolentzos/20a29b5af88d739ef2e7b524c144104cd5cfbf54> (Aug. 13, 2018).

Mihalcea, R., and Tarau, P. (2004). "TextRank: Bringing Order into Texts." *Proceedings of EMNLP 2004*, D. Lin and D. Wu, eds., Association for Computational Linguistics, Barcelona, Spain, 404–411.

Nguyen, M.-T., Kitamoto, A., and Nguyen, T.-T. (2015). "TSum4act: A Framework for Retrieving and Summarizing Actionable Tweets During a Disaster for Reaction." *Advances in Knowledge Discovery and Data Mining*, Lecture Notes in Computer Science, T. Cao, E.-P. Lim, Z.-H. Zhou, T.-B. Ho, D. Cheung, and H. Motoda, eds., Springer International Publishing, 64–75.

Olteanu, A., Castillo, C., Diaz, F., and Vieweg, S. (2014). "CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises." *Eighth International AAAI Conference on Weblogs and Social Media*.

Olteanu, A., Vieweg, S., and Castillo, C. (2015). "What to Expect When the Unexpected Happens: Social Media Communications Across Crises." *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing - CSCW '15*, ACM Press, Vancouver, BC, Canada, 994–1009.

Peng, S., Tseng, V. S., Liang, C.-W., and Shan, M.-K. (2018). "Emerging Product Topics Prediction in Social Media Without Social Structure Information." *Companion Proceedings of the The Web Conference 2018*, WWW '18, International World Wide Web Conferences Steering Committee, Republic and Canton of Geneva, Switzerland, 1661–1668.

Rudra, K., Banerjee, S., Ganguly, N., Goyal, P., Imran, M., and Mitra, P. (2016). "Summarizing Situational Tweets in Crisis Scenario." *Proceedings of the 27th ACM Conference on Hypertext and Social Media*, HT '16, ACM, New York, NY, USA, 137–147.

Rudra, K., Ghosh, S., Ganguly, N., Goyal, P., and Ghosh, S. (2015). "Extracting Situational Information from Microblogs During Disaster Events: A Classification-Summarization Approach." *Proceedings of the 24th ACM International on Conference on Information and Knowledge Management*, CIKM '15, ACM, New York, NY, USA, 583–592.

Rudra, K., Goyal, P., Ganguly, N., Mitra, P., and Imran, M. (2018). "Identifying Sub-events and Summarizing Disaster-Related Information from Microblogs." *The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval*, SIGIR '18, ACM, New York, NY, USA, 265–274.

Shu, K., Sliva, A., Wang, S., Tang, J., and Liu, H. (2017). "Fake News Detection on Social Media: A Data Mining Perspective." *SIGKDD Explor. Newsl.*, 19(1), 22–36.

Starbird, K., Spiro, E., Edwards, I., Zhou, K., Maddock, J., and Narasimhan, S. (2016). "Could This Be True?: I Think So! Expressed Uncertainty in Online Rumoring." *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, ACM Press, Santa Clara, California, USA, 360–371.

Vosoughi, S., Mohsenvand, M. `Neo', and Roy, D. (2017). "Rumor Gauge: Predicting the Veracity of Rumors on Twitter." *ACM Trans. Knowl. Discov. Data*, 11(4), 50:1–50:36.

Wang, S., Yan, Z., Hu, X., Yu, P. S., Li, Z., and Wang, B. (2016). "CPB: a classification-based approach for burst time prediction in cascades." *Knowledge and Information Systems*, 49(1), 243–271.

Wong, K.-F., Gao, W., and Ma, J. (2018). "Rumor Detection on Twitter with Tree-structured Recursive Neural Networks." *ACL*.

Zeng, L., Starbird, K., and Spiro, E. S. (2016). "Rumors at the Speed of Light? Modeling the Rate of Rumor Transmission During Crisis." *2016 49th Hawaii International Conference on System Sciences (HICSS)*, IEEE, Koloa, HI, USA, 1969–1978.

Zubiaga, A. (2018). "A longitudinal assessment of the persistence of twitter datasets." *Journal of the Association for Information Science and Technology*, 69(8), 974–984.

Zubiaga, A., Aker, A., Bontcheva, K., Liakata, M., and Procter, R. (2018a). "Detection and Resolution of Rumours in Social Media: A Survey." *ACM Comput. Surv.*, 51(2), 32:1–32:36.

Zubiaga, A., Kochkina, E., Liakata, M., Procter, R., Lukasik, M., Bontcheva, K., Cohn, T., and Augenstein, I. (2018b). "Discourse-aware rumour stance classification in social media using sequential classifiers." *Information Processing & Management*, 54(2), 273–290.

Zubiaga, A., Liakata, M., and Procter, R. (2016a). "Learning Reporting Dynamics during Breaking News for Rumour Detection in Social Media." *arXiv:1610.07363 [cs]*.

Zubiaga, A., Liakata, M., Procter, R., Hoi, G. W. S., and Tolmie, P. (2016b). "Analysing How People Orient to and Spread Rumours in Social Media by Looking at Conversational Threads." *PLOS ONE*, 11(3), e0150989.

Zubiaga, A., Spina, D., Amigó, E., and Gonzalo, J. (2012). "Towards real-time summarization of scheduled events from twitter streams." *Proceedings of the 23rd ACM conference on Hypertext and social media - HT '12*, ACM Press, Milwaukee, Wisconsin, USA, 319.

Information Uses and Gratifications Related to Crisis: Student Perceptions since the Egyptian Uprising

Steven D. Sheetz
Virginia Tech
sheetz@vt.edu

Andrea Kavanaugh
Virginia Tech
kavan@vt.edu

Edward A. Fox
Virginia Tech
fox@vt.edu

Riham Hassan
Arab Academy of Science and Technology e-
riham@aucegypt.edu

Seungwon Yang
Louisiana State University
seungwonyang@lsu.edu

Mohamed M. G. Farag
Arab Academy of Science and Technology e-
mmagdy@aast.edu

Donald Shoemaker
Virginia Tech
shoemake@vt.edu

ABSTRACT

People use diverse sources of information, e.g., newspapers, TV, Internet news, social media, and face-to-face conversations, to make sense of crises. We apply uses and gratifications theory (UGT) and structural equation modeling to illustrate how using internet-based information sources since the political uprisings in Egypt influence perceptions of information satisfaction. Consistent with expectations we find that content and process gratifications constructs combine to explain information satisfaction, while social gratifications do not significantly influence satisfaction in the context of a crisis. This suggests that UGT is useful for evaluating the use of information technology in a context where information is limited in quantity and reliability.

Keywords

Uses and gratifications theory; information sources; Internet; social media; structural equation modeling

INTRODUCTION

The popular uprisings that brought down governments in Tunisia, Egypt, and Libya, along with protests in other countries, became known as the 'Arab spring'. Political uprisings such as these are crises both for citizens and governments. Uses and gratifications theory (UGT) describes how information consumers use media to meet their information needs. UGT has been widely applied over time and more recently to assess the Internet (Stafford, Stafford et al., 2004), social media (Ku, Chu et al., 2013), and political information (Kaye and Johnson, 2002; Kaye and Johnson, 2004). UGT describes both how (through use of the different communication media and information

technology) and why (to achieve some purpose or need, i.e., gratification) a consumer pays attention to an information source.

Jamal and Melkote (2008) suggest that social gratifications are likely less relevant in crises than in normal non-crisis situations. They propose that process gratifications and content gratifications will dominate perceptions in the crisis context. Using partial least squares based structural equation modeling (PLS-SEM) we show that the expectations for traditional UGT constructs of content and process gratifications hold in our context of political uprisings, explaining a substantial amount of variance in our information satisfaction construct ($R^2 = .30$) and having significant positive influences on information satisfaction. Social gratifications has an inverse effect on satisfaction, rather than the expected positive effect hypothesized from prior Internet and social media research.

In the following section we provide background on the situation and expand on how the theory is relevant in the contexts of political uprisings. This is followed by sections for our hypotheses and research model, research methodology, presentation of measurement model, and results for our two structural models, discussion of the implications and limitations of our study, and summary conclusions.

BACKGROUND AND THEORY

Massive protests occurred in Egypt between January 25 and February 11, 2011 leading to the end of the Presidency of Hosni Mubarak. The government restricted cell phone access in Cairo and Alexandria during demonstrations, and cut off Internet access completely for several days (Singel, 2011), clearly attempting to limit the peoples' abilities to obtain and share information by restricting access to information sources. This is similar to the network disruptions that happen when communications infrastructure is destroyed in natural disasters, however in political uprisings technical disruptions are often a tool that governments use to suppress and control information. The resulting lack of information increases peoples' concerns about the accuracy and reliability of information they receive, ultimately driving their perceptions of information satisfaction.

Information sources in Egypt

There were many television stations, newspapers, and other information sources throughout Egypt at the time of the uprising. Internet adoption in Egypt was 43% in 2012 based on 2013 data from the International Telecommunications Union World Internet statistics (http://www.Internetworldstats.com/stats5.htm). Cell phones were a primary form of communication with an 87% adoption rate. The Internet also had diffused throughout Egypt's 86.9 million population, with Facebook reaching 14.5% of the population in 2012.

Young people (15-29 years old) were a large portion of the Egyptian population (about 33%) in 2012. These young people also were the largest group of Internet users, and users of social media in Egypt at the time (Mourtada and Salem, 2011). Muhtaseb and Frey (2008) apply UGT to Arab Americans' use of the Internet, finding that information-seeking was the most important motive for using the Internet followed by convenience, entertainment, to pass-time, and interpersonal motives including social enhancement. This suggests that our sample is likely primed to using the Internet prior to the emergence of a crisis, implying that they will turn to this resource when in need of information.

While the uprising impacted all of society, it is likely that the dissemination of information through the Internet and social media likely occurred disproportionately through this group (Kavanaugh et al., 2013). They pass along this information through face-to-face and cell phone interactions with older family members and friends. Thus, it is important to understand their perceptions of the information they receive to inform how information sources can be used effectively in the context of crisis situations.

Uses and Gratifications Theory

Uses and gratifications theory has a long history in the study of mass communication (Katz and Lazarsfeld, 1955, Katz et al., 1973). UGT argues that people use media and technology to fulfill specific needs, such as seeking information. Gratifications have been associated with specific media selection and use including: information-seeking, social interaction, relaxation, entertainment, passing time, and companionship (Katz, 1987). Our study draws on research applying UGT to Internet use, social media, and political information.

Stafford et al. (2004) identify a SEM model consisting of three constructs including content gratifications, process

gratifications, and social gratifications of the Internet. Content and process gratifications are defined as: "Content gratifications concern the messages carried by the medium, and process gratifications concern actual use of the medium itself," (Stafford et al., 2004, pg. 267). They include social gratifications due to the nature of communication over the Internet. They then test the measurement model, finding a good fit of their indicators with these constructs in the context of Internet use and confirming the relevance of the social gratifications construct.

We adopt the content, process, and social gratifications construct naming of Stafford et al. (2004) because they find a good fit for these constructs for modeling uses of the Internet. Perceptions of information accuracy and reliability are consistent with their content gratifications construct, while web browsing and surfing are part of their process gratifications construct. Finally, their social gratifications construct includes interactions with friends and other people using technology. These three constructs are consistent with our interest in how information is obtained related to crisis contexts, in this case a political uprising.

UGT applied to the Internet, Social Media, Political information

Permalee and Perkins (2012) applied a qualitative methodology to show that participants used their social network to trigger information-seeking activities on the Internet. Searchers focused on obtaining additional details on topics seen in traditional broadcast media and perceptions of media credibility triggered searches representing ideological diversity and politically diverse opinion.

Ji and Fu (2013) investigate how UGT influences affinity for the Internet and types of Internet content. They find that the affinities for the types of content are correlated and relate positively to social gratifications. Lin (2002) studies gratifications of online services and traditional broadcast media using regression analysis to find that information seeking and the interaction experiences are significant, predicting 39% of the likelihood of media use.

In a content analysis Pentina and Tarafdar (2014) find that social media contribute to and reduce information overload. Social media reduce information overload by providing a filtering of information socially curated by the network based on what others think is relevant. Yet, social media contributes to information overload by increasing the number of messages that must be processed, which implies an association between social and process gratifications. Whiting and Williams (2013) also use UGT to perform a qualitative study of social media. They find an emphasis on entertainment rather than information sharing and information seeking gratifications. Smock et al. (2011) describe a uses and gratifications approach to understanding SNS features using Facebook. They find information sharing and keeping in touch with friends and family motivations drive use of different features and use of Facebook overall. Cheung et al. (2011) include UGT constructs along with social influence and social presence in a SEM model to predict intention to use social media (R^2=0.28). Finding process and social gratifications significant, as well as social presence. However, they do not find content gratifications to be significant.

In a study of the adoption of social media, Pai & Arnott (2013) describe browsing, receiving instant responses, uploading pictures, and customizing as the primary uses of social media. They find that the highest gratifications for users is a sense of belonging, followed by hedonism, self-esteem, and reciprocity. Lee and Ma (2012) study news sharing in social media using UGT. Finding several hypotheses relating information seeking, socializing, and status seeking, along with prior sharing experience, significant for the intention to share news.

UGT has been applied to political information and understanding political activities in many studies. Findings from these studies indicate all UGT constructs contribute to motivations for using (Kaye & Johnson, 2002) and trust (Kaye & Johnson, 2004) in political information. Neubaum et al. (2014) examine sharing of emotions to find that active participation is associated with positive experiences such as feeling better, while passive usage was perceived as less beneficial. Macafee (2013) investigates the use of traditional and social media for political engagement. They find that only frequency of Facebook use is significant for explaining engagement; while TV, Print, and Internet news were not significant. Chung, et al. (2012) compare traditional and technological factors for determining online news credibility. They find that traditional factors of trustworthiness and expertise are the only significant factors driving use of online news sites of established news sources, e.g., New York Times and USA Today. While technology factors, e.g., hypertextuality, are significant for search sites including Google and Yahoo.

In summary, many studies that apply UGT to the Internet, social media, and political news use constructs consistent with the content, process, and social gratifications constructs. Our study applies these constructs in a model to assess their influence on information satisfaction in a crisis context.

RESEARCH MODEL AND HYPOTHESES

We use the construct names identified by Stafford et al. (2004) because they also make sense in our crisis context. Most importantly the process gratifications construct is measured by similar indicators as constructs named information-seeking or entertainment in other studies. Information-seeking is consistent with what we believe occurs related to crises, entertainment is not. Conceptually, browsing the Internet as an entertaining activity, is replaced by browsing the Internet to understand what is happening related to the crisis.

We extend their model by adding the information satisfaction construct used in prior research (Bailey and Pearson 1983, McKinney, Yoon et al. 2002, Wixom and Todd 2005) and hypotheses that relate each type of gratifications to this dependent variable. We define information satisfaction as a 2nd order formative construct consisting of dimensions of information availability and information influence dimensions. Table 1 presents our construct definitions (items for constructs are available upon request).

Information is always constrained in crisis. Sometimes these constraints are due to widespread damage to infrastructure, while in political situations governments may deliberately restrict or disable the Internet and other communications networks. Information availability refers to being able to access the information wanted and needed; higher perceptions of availability are indications of higher satisfaction with the information received. Information influence is our second dimension of information satisfaction. We expect that when people believe that their information was important for influencing their thinking about the crisis, they will also be more satisfied with that information.

Table 1: Construct Definitions: Content, Process, and Social Gratifications, and Information Satisfaction

Panel A: Uses and Gratifications Constructs	
Content	The degree to which the information/messages the participant obtained since the crises was accurate and reliable.
Process Gratifications deriving from the use of the Internet	
Internet Frequency	The frequency with which participants use the Internet for getting information about the crisis. Including how many hours per day, frequency of using video, social media, and Internet news sites.
Information Activities	The number of activities used to get information on the crises. Including the number of actions performed with cell phones, the social media features used, and types of Internet sites visited.
Social Gratifications deriving from the Internet as a social environment	
Sharing Internet	The degree to which the participant shares (receives) information obtained from the Internet with (from) their family and friends.
Sharing Frequency	The frequency with which the participant shares information obtained from all sources with their family and friends.
Panel B: Information Satisfaction Constructs	
Information Influence	The degree the information they obtained was important for influencing their thinking about political events.
Information Availability	The degree to which the participant was able to obtain all the information they needed and wanted.

Content Gratifications

Our first UGT hypothesis is that higher levels of information content gratifications lead to higher levels of information satisfaction. Information related to a crisis is hard to find and interpreting the information appropriately is difficult. Content gratifications in a non-crisis/normal situation is related to the areas identified by Stafford et al. (2004) including, education, learning, research, and knowledge. In crises, the focus is on information related to the issues in the situation, be it natural or man-made, and the other dimensions become less relevant. For example, using

the Internet for education and learning not related to the crisis is less important for those in such situations than information related to crisis response and management. A primary characteristic of the actual message is the perception that the information contained within it is accurate and reliable. When the content of the information is felt to be more accurate and reliable, information satisfaction should be higher, as should perceptions of information availability and the influence of the information. Thus, we propose Hypothesis H1:

H1: Content gratifications has a positive influence on information satisfaction.

Process Gratifications

We define Process Gratifications as a 2nd order formative construct consisting of dimensions of information seeking activities and the frequency of engaging in these activities. Process Gratifications in non-crisis situations are related to activities of using the Internet including searching, surfing, and using web sites (Stafford et al., 2004). In crises the process of obtaining information related to the issues in the situation is often complicated by compromises in network capabilities and other disruptions. Gratifications derived from the process are related to pursuing various activities frequently enough to feel the process is sufficient for obtaining the available information. That is, participants will engage in additional processes or perform more effective processes more frequently in crises, not solely for the experience of the process, but to have the feeling that the process provided the information that can be obtained. When people in the situation feel better about their processes for obtaining information and having the information that is available, their information satisfaction should be higher.

We also expect that more frequent exposure to information, even the same or erroneous information, will influence perception that the information is important and that it should influence thinking about the crisis. In addition, when the information obtained from frequent repetitive access of the Internet related to a crisis doesn't change or changes immaterially, perceptions that participants have the information available should emerge.

So, both the information activities and Internet frequency dimensions of process gratifications should influence the dimensions of information satisfaction. Thus, we propose Hypothesis H2:

H2: Process gratifications has a positive influence on information satisfaction.

Social Gratifications

Our third UGT hypothesis is that higher levels of social gratifications will lead to higher levels of information satisfaction. Social gratifications is defined as using the Internet to share information with others consisting of two dimensions. Sharing information from the Internet is an important aspect of our research due to the demographics of Egypt, with the younger people more likely having access to the Internet. We also expect that receiving and sending information from the Internet to and from family and friends increases connectedness and perceptions of information satisfaction. Higher levels of sharing should increase perceptions of having the information wanted, as sharing informs discussions of the information which should lead to assessment of information that is missing or needed. Further, we expect sharing to initiate interactions vetting the shared information, which should increase perceptions of the influence of that information.

Similarly, sharing information more frequently increases perceptions of the influence of that information and perceptions that you have the information that is available. More frequent interactions that include evaluations of the shared information should increase perceptions the information is important. Despite suggestions that social gratifications may not be as relevant in the context of crises, we follow the preponderance of UGT research on the Internet and social media use that indicates social gratifications likely influence information satisfaction in a positive manner. Thus, we propose Hypothesis H3:

H3: Social Gratifications has a positive influence on information satisfaction.

Social Gratifications influence on Process Gratification

Further we expect that obtaining Social Gratifications likely impacts Process Gratification. This is due to the need to have more and different processes for socially oriented information sharing activities beyond the normal process for information seeking. One result of the Arab spring was the perception that social media was influential in the process of the uprisings and their aftermath. The shut-down of the Internet during the uprising implies authorities were attempting to control information and limit sharing. This leads to an exploratory hypotheses relevant to UGT.

The hypothesis is that higher levels of social gratifications will lead to higher levels of process gratification. Sharing frequency involves social media, video sharing, and other activities that involve the Internet, clearly implying a relationship with Internet frequency. That is, more sharing activities will mean more online activity that could lead to other Internet sites. Similarly, more frequent sharing likely increases the number of Internet activities engaged.

Sharing information from the Internet also likely influences Internet frequency, since, to be shared, information must first be obtained from the Internet. A desire to share information from the Internet also may lead to more Internet activities. Thus, we propose Hypothesis H4:

H4: Social Gratifications has a positive influence on process gratification.

These four hypotheses are derived from the results of UGT studies of the Internet, social media, and political information discussed above. Figure 1 presents our research model.

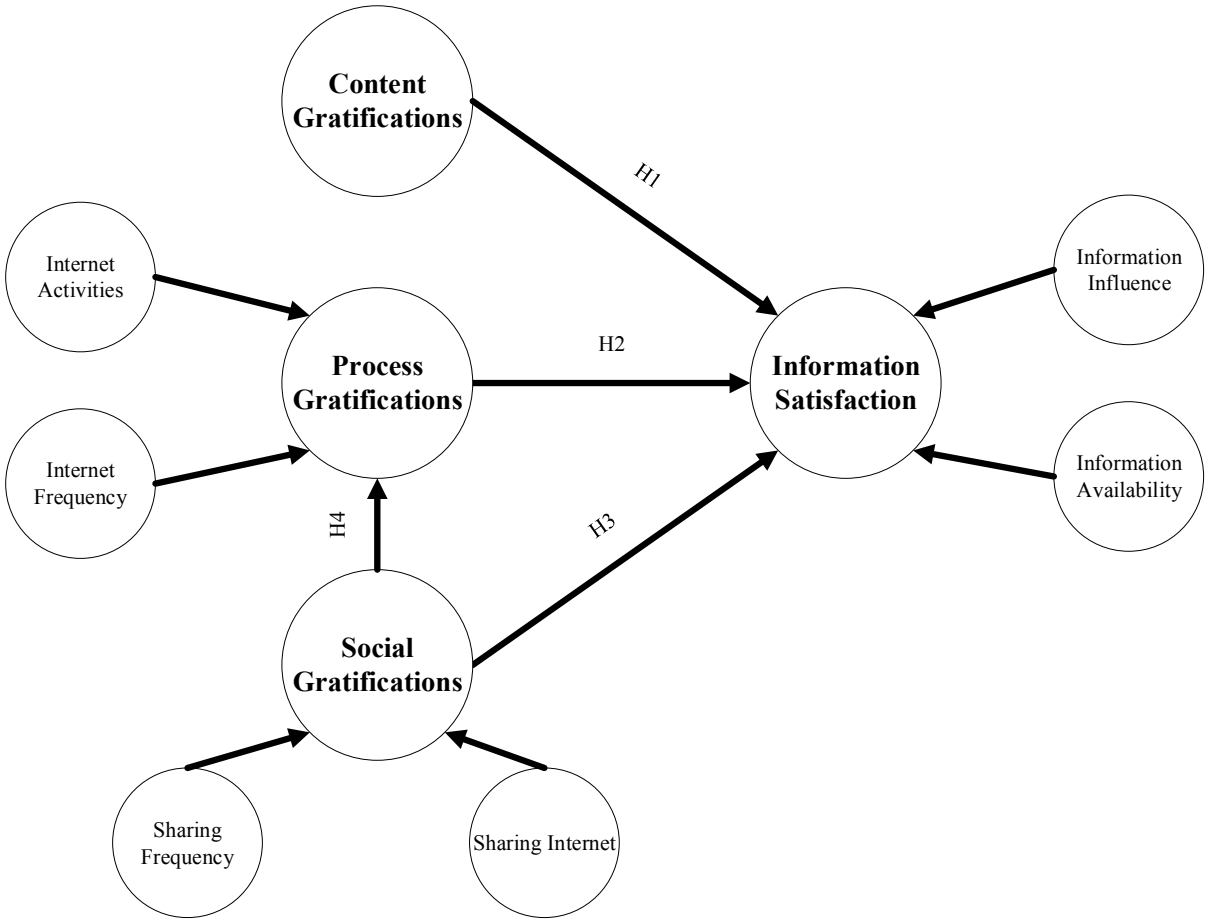


Figure 1: Information Uses and Gratifications in Crisis Research model.

METHOD

We adapted the survey from items used on previous studies applying UGT to investigate the use of the Internet and social media in particular (Kraut et al., 2002). Then we sent via email an invitation to participate in the survey for extra course credit or equivalent assignments to 500 students at a large university in Egypt. Students completed our online survey, which was transcribed into Arabic.

Our procedures for the web-based survey were consistent with the guidelines recommended by Punter, et al. (Punter, Ciolkowski, Freimut, & John, 2003) and (Singer & Vinson, 2002) for online software engineering surveys. Web-based surveys are less costly, more convenient, and provide more control than postal surveys (Couper, 2000). Moreover, web-based surveys have been shown to be similar to postal surveys in terms of the quality of data gathered (Bachmann, Elfrink, & Vanazza, 1996; Coderre, Mathieu, & St-Laurent, 2005), and the number of items answered (Bachmann et al., 1996; Coderre et al., 2005); also they are useful for reducing social desirability bias (Whitley, 2002).

Consistent with the recommendations of Bryant et al. (2004), we included controls to account for internal validity threats such as increased dropout rates and multiple submissions from the same participant. We encouraged participation in the study by describing the intent of the survey to the participants (Lazar & Preece, 1999). To control for the internal validity threat of multiple submissions from the same participant, participants were asked to provide their e-mail addresses; there were no duplicates received. To reduce item non-response, participants had to answer all questions in one section of the survey before proceeding to the next section.

RESULTS

The elections for the unicameral legislature held from November 2011-January 2012 were intended to resolve the crisis. However, the results of these elections were ruled to be illegitimate on June 14th 2012 by the Egyptian Supreme Court. We collected data in April and May 2012, between the election and the contentious ruling by the court. Thus, the resolution of the uprising had not yet occurred during the time our data was collected, even though it was 14 months after the initial uprising.

The survey was sent to 500 potential participants; a total of 204 participants attempted the survey and 170 students completed it, for a 34% response rate. There were more female (56%) than male respondents; most (89%) were single and lived in the city near the university or in nearby towns. Most (73%) had been using the Internet for 7 or more years, with 19% using the Internet for more than 10 years. Most (85%) were 19-21 years old and eligible to vote in Egypt.

We use partial least squares structural equation modeling (PLS-SEM) to test our research model. PLS-SEM is appropriate for our context because it is recommended for exploratory research, such as our unique application of UGT in crisis situations (Gopal, Bostrom, & Chin, 1992). The PLS-SEM measurement and structural models were assessed using smart PLS version 2.0 beta (Ringle, Wende, & Will, 2005).

Measurement Properties of Constructs

We first evaluated the measurement reliability and validity of the 1st order reflective constructs in our model. We assessed the scale reliabilities, along with convergent and discriminant validity of these constructs. Table 3 lists the descriptive statistics and scale measurement properties for these constructs. Scale reliability was assessed via composite reliability and Cronbach's alpha (Fornell & Larcker, 1981). As shown in Table 2, composite reliabilities are all well above the recommended 0.70 level, and Cronbach's alphas for the process and social gratifications constructs exceed the traditional 0.70 cutoff, while content and information influence exceed recommendations of .60 for exploratory research (Agarwal & Karahanna, 2000; Nunnally & Bernstein, 1994; Staples & Seddon, 2004). Although Information Availability at .58 is below the desired level, we maintain it due to high composite reliability (Hair et al., 2013).

Table 2: Construct means, standard deviations, and measures of internal consistency

Construct	# Items	Mean	Std. Dev.	AVE	Composite Reliability	Cron.'s Alpha[a]
Content Gratifications	3	2.88	0.58	0.58	0.85	0.76
Internet Frequency	4	6.00	2.96	0.65	0.88	0.81
Information Activities	3	4.19	1.45	0.62	0.83	0.70
Sharing Internet	2	2.88	1.58	0.95	0.97	0.94
Sharing Frequency	6	4.74	1.88	0.53	0.87	0.82
Information Influence	3	2.16	0.59	0.61	0.82	0.68
Information Availability	2	2.38	0.52	0.70	0.82	0.58

[a] Hair et al. (2014) and Ringle et al. (2005) indicate that Cronbach's alpha is not necessary for component based SEM implemented in PLS.

To determine convergent validity, all item loadings (outer loadings) should be greater than 0.70 (Agarwal & Karahanna, 2000) (Bassellier & Benbasat, 2004). We evaluated the cross loadings factor matrix from smart PLS (Ringle et al., 2005). Most of the items have loadings above the recommended 0.70 (Agarwal & Karahanna, 2000) (Bassellier & Benbasat, 2004). Seven items are below 0.70, yet above 0.60. Only one item, "the number of hours on the Internet per day (0.467), had a loading below 0.60 (text for indicators available from authors upon request). We retained this item due to the high scale reliability for the frequency of Internet use construct and content validity of the item. All items loaded more highly on their hypothesized construct when compared to any other construct. The t-statistics for all other item loadings are greater than 2.58, $p < .01$ (Gefen et al., 2000).

A further test of convergent validity is to determine if constructs have an average variance extracted (AVE) greater than or equal to 0.50, indicating at least 50% of the indicator variables' variance is determined by the latent variable (Chin, 1998). Our 1st order reflective constructs meet this requirement, as shown in Table 2.

We also used an AVE test to establish both discriminant and convergent validity of these constructs (Fornell & Larcker, 1981; Netemeyer, Johnston, & Burton, 1990). The diagonal elements of the matrix in Table 3 contain the square root of the AVE estimates for each construct; the off-diagonal elements are the correlations between constructs. Validity is achieved if the AVE estimates for both constructs are greater than the correlation of the two constructs. The diagonal elements are all larger than their corresponding correlation coefficients, indicating that these constructs all demonstrate convergent validity and discriminant validity (D. Gefen, D. Straub, & M. Boudreau, 2000).

Table 3: Construct correlations and square-root of AVE values on diagonal.

	Info Activities	Content	Internet Frequency	Info Influence	Sharing Internet	Info. Availability	Sharing Freq.
Info Activities	**0.790**						
Content	0.134	**0.837**					
Internet Freq.	0.723	0.119	**0.809**				
Info Influence	0.302	0.217	0.245	**0.779**			
Sharing Internet	0.313	0.075	0.455	-0.124	**0.973**		
Info Availability	0.314	0.418	0.281	0.199	0.196	**0.838**	
Sharing Freq	0.449	0.179	0.368	0.368	0.013	0.059	**0.727**

We conducted a power analysis to ensure our ability to find the hypothesized effects if present. Hair et al. (2013) recommend Cohen's (Cohen, 1988) 80% likelihood for detecting effects approach for determining the sample size needed when using PLS-SEM, while others recommend at least 10 times the largest number of paths affecting a dependent construct in the model (Chin, 1998). Our sample, comprised of 170 observations, is consistent with detecting R^2 values of 0.10 at a 0.05 level of significance for a model with a maximum of 3 paths influencing any one dependent construct (Hair et al., 2013, p. 21), thereby ensuring an adequate level of power.

Results for Structural Models

The second step in PLS-SEM analysis determines which of the hypothesized relationships in the model are significant, and the relative strengths of the significant influences. We first evaluate the highly parsimonious UGT model developed above, then decompose the formative endogenous satisfaction construct as recommended by Cadogan and Lee (Cadogan & Lee, 2013).

We evaluated the structural models for effects on information satisfaction using coefficient of determination (R^2) values and in terms of the significance and relative values of the path coefficients (Kishore & McLean, 2007) (D. Gefen, D. Straub, & M.-C. Boudreau, 2000). The following subsections present the results for the initial and decomposed structural models.

Initial Structural Model

Figure 2 shows the R^2 values, path coefficients, and their significance levels calculated by SmartPLS 2.0 beta (Ringle et al., 2005) for the initial structural model that tests the fundamental propositions of UGT. The model explains 30% of the variance in information satisfaction, indicating a weak yet significant level of explanation (Hair et al., 2013). In addition, the social gratifications construct significantly influences the process gratifications construct, explaining 33% of its variance.

The path coefficient for the relationship showing the effect of the content construct on information satisfaction is significant (0.392, $t = 6.056$, $p < 0.01$), as shown in Figure 2, supporting H1. Hypothesis H2 relating influence of process gratifications on information satisfaction also is supported (0.404, $t = 4.806$, $p < 0.01$). The influence of social gratifications on information satisfaction was marginally significant (-0.109, $t = 1.296$, $p < 0.10$), however the sign of the coefficient is negative rather than positive as hypothesized, thus H3 is not supported.

We investigated whether process gratifications is mediating the influence of social gratifications as described by Hair et al. (2013), pg. 224. After removing process gratifications from the model the path coefficient from social gratifications to information satisfaction is not significant, thus process gratifications is not mediating social gratification. Thus, hypothesis H4 is supported as social gratifications does have a substantive influence on process gratifications (0.578, $t = 12.309$, $p < 0.01$).

Support for three of four hypotheses and explaining 30% of the variance in information satisfaction indicates that UGT is applicable for understanding information use in crises, such as the uprisings and subsequent events in Egypt. In addition, the social gratifications influence on information satisfaction hypothesis that is not supported, was previously suggested to not be relevant in the crisis context (Jamal & Melkote, 2008).

This result suggests one way the use of information in a crisis context is different than in non-crisis contexts where UGT was developed.

In the past our analyses may have ended with this highly parsimonious and UGT congruent result. However, recent measurement research (Cadogan & Lee, 2013; Rigdon, 2014) suggests that dependent variables consisting of higher order endogenous formative constructs can provide potentially misleading results. Since our primary dependent endogenous variable information satisfaction is formative, we decided to evaluate a second model where it is replaced with its 1st order dimensions of information availability and information influence.

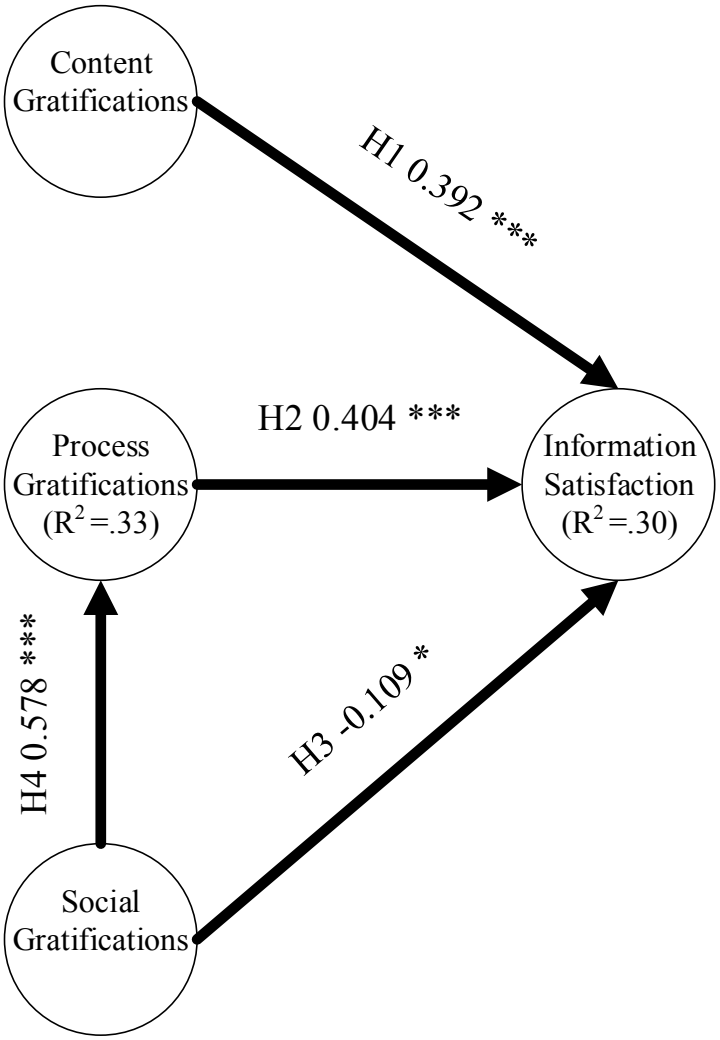


Figure 2: Information Uses and Gratifications in Crisis structural model

Dimensions of Information Satisfaction Structural Model

Evaluating the dimensions of Information Satisfaction means replacing one formative construct with two reflective constructs of information availability and information influence. Each of these constructs has the same paths predicting them as did the higher order information satisfaction construct. The individual dimensions are not as well explained in this model, with information availability having $R^2 = 0.24$ and influence of information having $R^2 = 0.12$; recall that information satisfaction in the initial model has $R^2 = 0.30$. The social gratifications construct also significantly influences the process gratifications construct in this model, explaining 32% of its variance. Figure 3 shows the revised model.

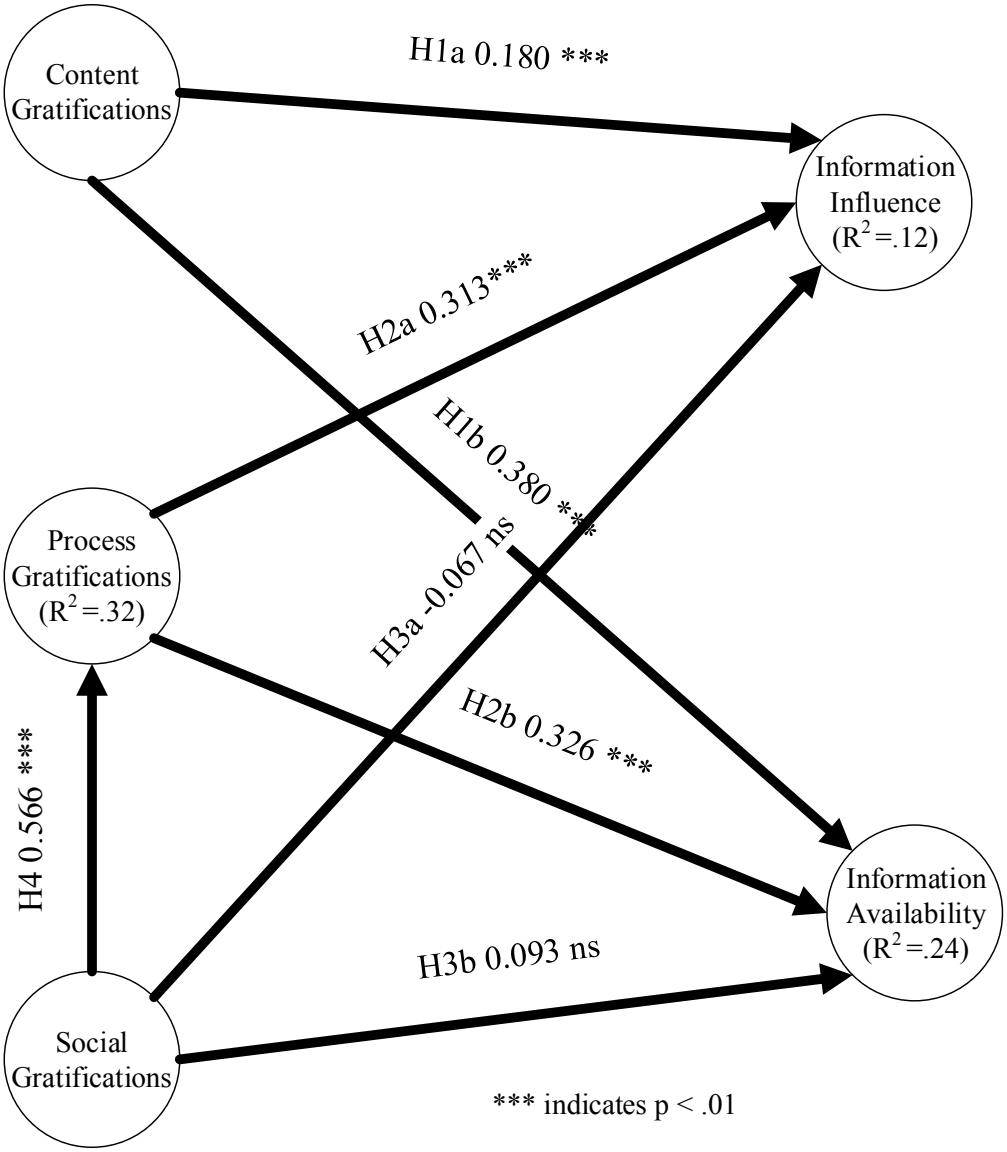


Figure 3: Structural model of dimensions of information satisfaction.

The path coefficients in the decomposed model are consistent with those in the initial model. Content gratifications is a significant contributor to both dimensions of information satisfaction, impacting information influence, i.e., H1a, (0.180, t = 2.673, p < 0.01) and information availability, i.e., H1b, (0.380, t = 5.421, p < 0.01). Process gratifications significantly impacts information influence, i.e., H2a (0.313, t = 4.112, p < .01) and information availability, i.e., H2b, (0.326, t = 4.167, p < 0.01), with nearly equivalent coefficients. Hypothesis H4, that social gratifications influence process gratifications is the same as in the prior model and significant (0.566, t = 10.574, p < 0.01). Thus, hypotheses H1, H2, and H4 are again supported.

Social Gratifications do not significantly impact information influence, i.e., H3a, (-0.067, t=0.416, p ns) or information availability, i.e., H3b (-0.093, t=1.062, p ns), thus not supporting these sub-hypotheses. This suggests again that the crisis context somehow limits the potential for Social Gratifications to lead to Information Satisfaction. These results confirm that the UGT model of information satisfaction in crisis situations is supported overall at two levels of abstraction.

DISCUSSION

In summary, our results suggest several observations. First, higher perceptions of the accuracy and reliability of the information, i.e., content gratifications, are associated with perceptions of higher information satisfaction. Further, content gratifications significantly effect the information availability and the influence of the information dimensions of information satisfaction. Content gratifications has the largest effect of any construct on information availability, and a stronger influence on information availability than on the influence of the information. Indicating perceptions of information availability will increase if the accuracy and reliability of the information obtained can be increased. Specifically recognizing the variability in the accuracy and reliability of information and explicitly considering how to evaluate it may facilitate users' perceptions of knowing when sufficient information is available. Accuracy and reliability also affect the influence of the information, such that more accurate and reliable information will be more important for influencing thinking. We expect the source, e.g., government or independent TV stations, of the information will be one aspect of the information that will be used to judge accuracy and reliability.

Second, process gratifications is predictive of information satisfaction, positively impacting information availability and how influential the information is perceived and the largest impact of any construct on the influence of information. Process gratifications consists two dimensions including the number of information activities engaged and the frequency of those activities. We examined another model (figure not included) where the process gratifications construct was decomposed into its dimensions, finding similar R^2 values for information availability (R^2=0.24) and the influence of information(R^2=0.13). The dimension of internet activities has path coefficients of (0.212, t = 2.473, p < .01) for information availability and (0.281, t = 2.925, p < .01) for the influence of information, while the frequency of internet activities has path coefficients of (0.145, t = 1.686, p < .10), for information availability and (0.061, t = 0.510, p ns), for the influence of information. This suggests that users pay relatively more attention to the number of varying search activities they pursue, rather than the frequency of searching. By increasing the variety of search activities people cast a wider net and should increase perceptions of both information availability and the influence of the information. Participating in different activities has the potential for confirming or contradicting information originating from multiple sources. Finding the same or similar information from multiple activities, i.e., confirming, may indicate that the information available has been obtained, while finding differing information, i.e., contradicting, may imply that more information is available or needed. Similar effects may apply to the influence of the information, with contradicting information suggesting lower influence and confirming information suggesting higher influence. The frequency of activities does not significantly affect the influence of information, perhaps this is due to finding the same information from the same activities, i.e., confirming, is not as satisfying as confirming across activities. In addition, the more frequently the same information is found reduces the amount of different information obtained, i.e., the potential for finding contradicting information is lower. Overall it seems doing the same things more frequently may not provide much marginal satisfaction.

Third, social gratifications were speculated to not be influential in a crisis context (Jamal and Melkote, 2008); our results support this previous speculation. Our finding a negative path coefficient for hypothesis H3 implies that more frequent sharing and more sharing with friends and family of information obtained through the Internet reduces satisfaction with that information. This seems a fundamental disconnect with the widespread use of the Internet for social purposes and is inconsistent with prior UGT research on why people use the Internet and the social gratifications they receive. To understand this in more detail, we examined another model (figure not included) where the social gratifications construct was decomposed into its dimensions, finding a similar R^2 value for information availability (R^2=0.24) and a higher value for influence of information (R^2=0.21). The dimension of sharing activities has path coefficients of (0.028, t = 0.404, p ns) for information availability and (-0.272, t = 4.279, p < .01) for the influence of information, while the frequency of sharing has path coefficients of (-0.160, t = 2.420, p < .01), for information availability and (0.148, t = 1.660, p < .10), for the influence of information. Thus, the subdimensions of social gratifications have inverse effects on different subdimensions of information satisfaction that in the higher order model combine for an overall inverse impact on satisfaction. Higher sharing activity information with friends and family drives lower the influence of information, while the more frequent activities reduces perceptions of information availability.

Our results are consistent with many prior UGT studies related to using the Internet (Ku et al., 2013; Lee & Ma, 2012; Parmelee & Perkins, 2012; Stafford et al., 2004), social media (Ku et al., 2013; Lee & Ma, 2012; Lenhart & Madden, 2007; Macafee, 2013), and political information (Barbara K Kaye & Johnson, 2002; Barbara K. Kaye &

Johnson, 2004; Lariscy et al., 2011; Parmelee & Perkins, 2012). Specifically, we support the theory by finding the constructs valid and reliable in data from another context. Further, we confirm primary hypotheses relating gratifications to information satisfaction, while uncovering a situation where social gratifications are not as influential as expected.

The limitations of our study involve our opportunity sample and our web-based survey methodology. We have attempted to control for the vulnerabilities of the web-based survey as described in the methods section and believe that many of those concerns have been controlled. Our sample makes generalizing beyond young people and college students difficult, however they experienced the uprising and are likely representative of the users of the Internet and social media in Egypt. Further, we feel it is important to understand the perceptions of the young adults given their large proportion of the population in Egypt and many of the other countries involved in the Arab Spring. Our data were collected well after the original uprising, yet it was during the time when the 1st cameral election was invalidated by the supreme court. Which we believe is part of the extended crisis that resulted from the uprising.

CONCLUSION

Uses and gratifications theory can be applied to the use of information sources related to crises. Individuals searching for information related to crisis should 1) identify the information they want and how they'll know it is accurate; and 2) maximize the number of different activities for information-seeking rather than focusing on frequency of a few activities; and 3) beware of potential for information sharing activities to reduce their information satisfaction. Why the impact of social gratifications on information satisfaction hypothesized by UGT seems to be suppressed in the context of this crisis is a topic for future research.

ACKNOWLEDGMENTS

We thank the National Science Foundation NSF for supporting this work via the grant: III:Small:Integrated Digital Library Support for Crisis, Tragedy, and Recovery, Award #: 0916733

REFERENCES

Agarwal, R., & Karahanna, E. (2000). Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage. *MIS Quarterly*, 665-694.

Bachmann, D., Elfrink, J., & Vanazza, G. (1996). Tracking the Progress of E-mail vs. Snail-mail. *Marketing Research, 8*(2), 30-35.

Bailey, J. E., & Pearson, S. W. (1983). Development of a Tool for Measuring and Analyzing Computer User Satisfaction. *Management Science, 29*(5), 530-545.

Bassellier, G., & Benbasat, I. (2004). Business competence of information technology professionals: conceptual development and influence on IT-business partnerships. *MIS Quarterly*, 673-694.

Bryant, S. M., Hunton, J. E., & Stone, D. N. (2004). Internet-based Experiments: Prospects and Possibilities for Behavioral Accounting Research. *Behavioral Research in Accounting, 16*(1), 107-129.

Cadogan, J. W., & Lee, N. (2013). Improper use of endogenous formative variables. *Journal of Business Research, 66*(2), 233-241.

Cheung, C. M., Chiu, P.-Y., & Lee, M. K. (2011). Online social networks: Why do students use facebook? *Computers in Human Behavior, 27*(4), 1337-1343.

Chin, W. W. (1998). The partial least squares approach to structural equation modeling. In G. A. Marcoulides (Ed.), *Modern Methods for Business Research* (pp. 295-336). Mahway, New Jersey: Lawrence Erlbaum.

Chung, C. J., Nam, Y., & Stefanone, M. A. (2012). Exploring online news credibility: The relative influence of traditional and technological factors. *Journal of Computer-Mediated Communication, 17*(2), 171-186.

Coderre, G., Mathieu, A., & St-Laurent, N. (2005). Comparison of the Quality of Quantitative Data Obtained Through Telephone, Postal and Email Surveys. *International Journal of Market Research, 46*, 347-357.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Couper, M. (2000). Web Surveys: A Review of Issues and Approaches. *Public opinion quarterly, 64*(4), 464-494.

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly, 13*(3), 318-340.

Fornell, C., & Larcker, D. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research, 18*, 39-50.

Gefen, D., Straub, D., & Boudreau, M. (2000). Structural Equation Modeling and Regression: Guidelines for Research Practice. *Communications of the Association of Information Systems, 4*(7), 1-79.

Gopal, A., Bostrom, R. P., & Chin, W. W. (1992). Applying adaptive structuration theory to investigate the process of group support systems use. *Journal of Management Information Systems*, 45-69.

Hair Jr, J. F., Hult, G. T. M., Ringle, C., & Sarstedt, M. (2013). *A primer on partial least squares structural equation modeling (PLS-SEM)*: Sage Publications.

Hughes, A., Palen, L., Sutton, J., Liu, S., & Vieweg, S. (2008). *'Site-Seeing'in Disaster: An Examination of On-Line Social Convergence.* Paper presented at the *Proceedings of the 5th International ISCRAM Conference*, Washington, DC.

Hughes, A. L., & Palen, L. (2009). Twitter adoption and use in mass convergence and emergency events. *International Journal of Emergency Management, 6*(3), 248-260.

Jamal, A., & Melkote, S. R. (2008). Viewing and avoidance of the Al-Jazeera satellite television channel in Kuwait: A uses and gratifications perspective. *Asian Journal of Communication, 18*(1), 1-15.

Ji, P., & Wayne Fu, W. (2013). Love Internet, love online content: Predicting Internet affinity with information gratification and social gratifications. *Internet Research, 23*(4), 396-413.

Katz, E. (1987). Communication research since Lazarsfeld *Public opinion quarterly, 51*, 525-545.

Katz, E., Blumler, J. G., & Gurevitch, M. (1973). Uses and gratifications research. *Public opinion quarterly*, 509-523.

Katz, E., & Lazarsfeld, P. F. (1955). *Personal influence: the part played by people in the flow of mass communications*. Glencoe, IL: Free Press.

Kaye, B. K., & Johnson, T. J. (2002). Online and in the know: Uses and gratifications of the web for political information. *Journal of Broadcasting & Electronic Media, 46*(1), 54-71.

Kaye, B. K., & Johnson, T. J. (2004). A Web for all reasons: uses and gratifications of Internet components for political information. *Telematics and Informatics, 21*(3), 197-223. doi: 10.1016/s0736-5853(03)00037-6

Kishore, R., & McLean, E. R. (2007). Reconceptualizing innovation compatibility as organizational alignment in secondary IT adoption contexts: an investigation of software reuse infusion. *Engineering Management, IEEE Transactions on, 54*(4), 756-775.

Kraut, R., Kiesler, S., Bonka, B., Cummings, J., Helgeson, V., & Crawford, A. (2002). Internet Paradox Revisited. *Journal of Social Issues, 58*(1), 49-74.

Ku, Y.-C., Chu, T.-H., & Tseng, C.-H. (2013). Gratifications for using CMC technologies: A comparison among SNS, IM, and e-mail. *Computers in Human Behavior, 29*(1), 226-234. doi: 10.1016/j.chb.2012.08.009

Lazar, J., & Preece, J. (1999). Designing and Implementing Web-based Surveys. *Journal of Computer Information Systems, 39*(4), 63-67.

Lee, C. S., & Ma, L. (2012). News sharing in social media: The effect of gratifications and prior experience. *Computers in Human Behavior, 28*(2), 331-339. doi: 10.1016/j.chb.2011.10.002

Lenhart, A., & Madden, M. (2007). Social networking websites and teens: An overview. Washington, DC: Pew Internet & American Life

Lin, C. A. (2002). Perceived gratifications of online media service use among potential users. *Telematics and Informatics, 19*(1), 3-19.

Luo, M. M., Chea, S., & Chen, J.-S. (2011). Web-based information service adoption: A comparison of the motivational model and the uses and gratifications theory. *Decision Support Systems, 51*(1), 21-30.

Macafee, T. (2013). Some of these things are not like the others: Examining motivations and political predispositions among political Facebook activity. *Computers in Human Behavior, 29*(6), 2766-2775. doi: 10.1016/j.chb.2013.07.019

McKinney, V., Yoon, K., & Zahedi, F. (2002). The Measurement of Web-Customer Satisfaction: An Expectation and Disconfirmation Approach. *Information Systems Research, 13*(3), 296-315.

Mourtada, R., & Salem, F. (2011). Facebook Usage: Factors and analysis. In D. S. o. Government (Ed.), *Arab Social Media Report* (Vol. 1). Dubai: Dubai School of Government.

Muhtaseb, A., & Frey, L. R. (2008). Arab Americans' motives for using the Internet as a functional media alternative and their perceptions of US public opinion. *Journal of Computer-Mediated Communication, 13*(3), 618-657.

Netemeyer, R. G., Johnston, M. W., & Burton, S. (1990). Analysis of role conflict and role ambiguity in a structural equations framework. *Journal of Applied Psychology, 75*(2), 148.

Neubaum, G., Rösner, L., Rosenthal-von der Pütten, A. M., & Krämer, N. C. (2014). Psychosocial functions of social media usage in a disaster situation: A multi-methodological approach. *Computers in Human Behavior, 34*, 28-38.

Nunnally, J. Bernstein, IH (1994). Psychometric theory: New York: McGraw-Hill.

Pai, P., & Arnott, D. C. (2013). User adoption of social networking sites: Eliciting uses and gratifications through a means–end approach. *Computers in Human Behavior, 29*(3), 1039-1053.

Palen, L., Vieweg, S., Liu, S., B., & Hughes, A. L. (2009). Crisis Informatics: Studying Crisis in a Networked World. *Social Science Computer Review, 27*(4), 467-480.

Parmelee, J. H., & Perkins, S. C. (2012). Exploring social and psychological factors that influence the gathering of political information online. *Telematics and Informatics, 29*(1), 90-98. doi: 10.1016/j.tele.2010.12.001

Pentina, I., & Tarafdar, M. (2014). From "information" to "knowing": Exploring the role of social media in contemporary news consumption. *Computers in Human Behavior, 35*, 211-223.

Punter, T., Ciolkowski, M., Freimut, B., & John, I. (2003). *Conducting On-Line Surveys in Software Engineering.* Paper presented at the Proceedings of the International Symposium on Empirical Software Engineering (ISESE '03), Washington, DC.

Rigdon, E. E. (2014). Comment on "Improper use of endogenous formative variables". *Journal of Business Research, 67*(1), 2800-2802.

Ringle, C. M., Wende, S., & Will, A. (2005). SmartPLS 2.0 (beta): Hamburg.

Ruggiero, T. E. (2000). Uses and gratifications theory in the 21st century. *Mass communication & society, 3*(1), 3-37.

Schneider, S. M., & Foot, K. A. (2004). Crisis communication and new media: The Web after September 11th. In P. N. Howard & S. J. Jones (Eds.), *Society Online The Internet in Context* (pp. 137-153): Thousand Oaks: Sage.

Sheetz, S., Kavanaugh, A., Quek, F., Kim, B. J., & Lu, S.-C. (2010). The Expectation of Connectedness and Cell Phone Use in Crises. *International Journal of Emergency Management, 7*(2), 124-136.

Singel, R. (2011). Report: Egypt shut down net with big switch, not phone calls. *Retrieved December, 5*, 2013.

Singer, J., & Vinson, N. G. (2002). Ethical Issues in Empirical Studies of Software Engineering. *IEEE Transactions on Software Engineering, 28*, 1171-1180.

Smock, A. D., Ellison, N. B., Lampe, C., & Wohn, D. Y. (2011). Facebook as a toolkit: A uses and gratification approach to unbundling feature use. *Computers in Human Behavior, 27*(6), 2322-2329.

Stafford, T. F., Stafford, M. R., & Schkade, L. L. (2004). Determining uses and gratifications for the Internet. *Decision Sciences, 35*(2), 259-288.

Staples, D. S., & Seddon, P. (2004). Testing the technology-to-performance chain model. *Journal of Organizational and End User Computing (JOEUC), 16*(4), 17-36.

Venkatesh, V., Morris, M., Davis, G. B., & Davis, F. D. (2003). User acceptance of Information technology: Toward a unified view. *MIS Quarterly, 27*(3), 425-478.

Whiting, A., & Williams, D. (2013). Why people use social media: a uses and gratifications approach. *Qualitative Market Research: An International Journal, 16*(4), 362-369.

Whitley, B. (2002). *Principles of Research in Behavioral Science* (second ed.). New York: McGraw-Hill.

Wixom, B. H., & Todd, P. A. (2005). A theoretical integration of user satisfaction and technology acceptance. *Information Systems Research, 16*(1), 85-102.

Appendix 1: Indicators of model constructs.

Code	Content Gratifications Items
CON1[a]	Overall, information I was able to get was accurate since the uprising (March 2011 - March 2012). (six point scale strongly disagree to strongly agree)
CON2[a]	The news and information about events I received was reliable since the uprising (March 2011 - March 2012).
CON3[a]	The information I was able to get was not reliable since the uprising (March 2011 - March 2012). (reversed)
	Process Gratification: Internet Activities
PGIA1	What Internet sites did you visit? (check all that apply, ***number checked***) (Facebook pages on the uprising (e.g., we are all Khaled Saed), Twitter - a person you follow, Twitter - an organization you follow, Newspaper websites (e.g., Al Masry Alyoum, Al Youm Al Sabea, etc.), Television News channel websites, News websites (e.g., Masarawy), Other)
PGIA2	Since the uprising (March 2011 - March 2012), which of the following features did you use on Social Networking Sites? (check all that apply, ***number checked***) (Post comments, Post pictures or videos, Physically show others your site, Join groups, Read others' posts, Look at the site information of others, Update my status, Other)
PGIA3	Since the uprising (March 2011 - March 2012), which of the following activities did you do on a cell phone? (check all that apply, ***number checked***) (Make or receive phone calls, Send or receive a text message, Take a picture, Take a video, Send a picture or video to another person, Send a picture or video to an organization, Look at a picture or video from another person, Browse the Internet, Other)
	Process Gratification: Internet Frequency
PGIF1	On a typical day since the uprising (Mar.2011 - Mar. 2012), about how many hours a day were you using the Internet? Include time spent on instant messaging, email, browsing the Internet, and on social networking sites, for work and personal reasons. (***number of hours***)
PGIF2[b]	How often since the uprising (March 2011 - March 2012) were you looking at video or photo sharing websites, e.g., YouTube or Flickr?
PGIF3[b]	How often since the uprising (March 2011 - March 2012) were you using Social Networking sites, e.g., Facebook?
PGIF4[b]	How often since the uprising (March 2011 - March 2012) were you using the Internet?

[a] Measured on: strongly disagree to strongly agree.

[b] Measured on a scale of: almost never, < once per month, about once per month, several times per month, about once per week, serveral times per week, about once per day, several times per day.

Social Gratification	
Code	**Social Gratification: Sharing Activities**
SGSA1[a]	I shared information that I obtained from the Internet (including Facebook, Youtube, Twitter, etc.) with other family members and friends?
SGSA2[a]	Other family members and friends shared information with me that they obtained from the Internet (including Facebook, YouTube or Twitter)?
	Social Gratification: Sharing Frequency
SGSF1[b]	How often did you use email to communicate (share information) with any of your friends and family?
SGSF2[b]	How often did you use a cell phone text message to communicate (share information) with any of your friends and family?
SGSF3[b]	How often did you use a cell phone voice calls to communicate (share information) with any of your friends and family?
SGSF4[b]	How often did you use instant messaging to communicate (share information) with any of your friends and family?
SGSF5[b]	How often did you use a social networking site to communicate (share information) with any of your friends and family?
SGSF6[b]	How often did you use an Internet communication service, e.g., Skype, to communicate (share information) with any of your friends and family?
Information Satisfaction	
	Information Satisfaction: Influence
ISII1[c]	How important has been the information you received from social networking sites, e.g., Facebook, as an influence on your thinking about these events.
ISII2[c]	How important has been the information you received from Internet video sharing sites, e.g., Youtube, as an influence on your thinking about these events.
ISII3[c]	How important has been the information you received from Internet news sites, e.g., Newspaper websites, TV channel websites, Facebook news pages, or News websites (Masarwy), as an influence on your thinking about these events.
	Information Satisfaction: Information Availability
ISIA1[a]	I was not able to get the information I needed since the uprising (March 2011 - March 2012). (reversed)
ISIA2[a]	I was able to get the information I wanted since the uprising (March 2011 - March 2012).

[c] Measured on a four point scale: not at all important, not too important, somewhat important, very important.

TREC Incident Streams: Finding Actionable Information on Social Media

Richard McCreadie*
University of Glasgow†
richard.mccreadie@glasgow.ac.uk

Cody Buntain
New York University‡
cody@bunta.in

Ian Soboroff
National Institute of Standards and Technology (NIST)§
ian.soboroff@nist.gov

ABSTRACT

The Text Retrieval Conference (TREC) Incident Streams track is a new initiative that aims to mature social media-based emergency response technology. This initiative advances the state of the art in this area through an evaluation challenge, which attracts researchers and developers from across the globe. The 2018 edition of the track provides a standardized evaluation methodology, an ontology of emergency-relevant social media information types, proposes a scale for information criticality, and releases a dataset containing fifteen test events and approximately 20,000 labeled tweets. Analysis of this dataset reveals a significant amount of actionable information on social media during emergencies (> 10%). While this data is valuable for emergency response efforts, analysis of the 39 state-of-the-art systems demonstrate a performance gap in identifying this data. We therefore find the current state-of-the-art is insufficient for emergency responders' requirements, particularly for rare actionable information for which there is little prior training data available.

Keywords

Emergency Management, Crisis Informatics, Real-time, Twitter, Categorization

INTRODUCTION

Mass adoption of mobile devices paired with wide-spread use of social media platforms has created new ways for the public to contact response services (Castillo 2016). Research has shown that 69% of people expect responders to answer calls for help made from these additional channels (O'Dell 2011). In response, emergency and civil protection services are increasingly looking for ways to monitor these channels, answer questions, provide advice, respond to aid requests, and report other useful information to the Incident Commander (FEMA 2013). Monitoring these social media channels is a nontrivial task, however, given the volume of information posted on these platforms and the need to categorise, cross-reference and verify the information contained therein (Castillo 2016).

The combined issues of data volume and public expectation demonstrate a clear need for computer-supported tools to assist response officers. To this end, researchers have invested significant effort into models for categorizing social media content, such as for finding affected people (Imran, Elbassuoni, et al. 2013), analysing infrastructure damage (Truelove et al. 2015) or identifying eyewitness accounts (Olteanu, Castillo, et al. 2014; Diakopoulos et al. 2012). Additionally, a number of platforms such as AIDR (Imran, Castillo, et al. 2014), CrisisTracker (Rogstadius et al. 2013), Twitcident (Abel et al. 2012) and EPIC Analyse (Barrenechea et al. 2015) have been developed.

These technologies have had limited impact on emergency management practice, primarily due to questions of data quality (Hiltz et al. 2014), insufficient trained staff (Plotnick et al. 2015), fear of commitment to social media

*corresponding author
†http://gla.ac.uk and http://dcs.gla.ac.uk/~richardm
‡http://cody.bunta.in/
§https://www.nist.gov/ and https://www.nist.gov/people/ian-soboroff

as a primary communication channel (Tapia et al. 2013), and incompatibility with organizational policy (Reuter, Heger, et al. 2013). Indeed, a recent study of ISCRAM papers concluded this research has had "a relatively small contribution to actual technology and industry" (Reuter, Backfried, et al. 2018).

While questions of training, commitment, and policy are organizational in nature, we argue the research community can solve *data quality* issues through: 1) standardizing social media analytics tasks; 2) standardizing datasets used to evaluate these tasks; and 3) focusing research efforts on advancing technical readiness and deployability. In particular, by defining a small number of standard social media analytic tasks that are well aligned with the needs of emergency response officers, it becomes feasible to construct datasets with sufficient size and robustness to confidently quantify tool accuracy (and hence resultant data quality). Then, by bringing together international researchers to work on those tasks and datasets, we can incrementally raise the quality of our solutions to a level where potential end users will be willing to use those solutions.

In this paper, we describe the new Incident Streams (TREC-IS) initiative, aimed at achieving this standardization. This initiative is part of the Text REtrieval Conference (TREC)[1] and sponsored by the Public Safety Communications Research program at the US National Institute of Standards and Technology (NIST, US). TREC-IS aims to develop test collections and evaluation methodologies for automatic and semi-automatic filtering approaches that identify and categorize information and aid-requests made on social media during crises. The end goals are: to advance the technology readiness level (TRL) of current social media crisis monitoring solutions; better support social media monitoring by emergency response officers and other stakeholders; and bring together researchers from across the globe to work on this problem by providing an annual evaluation challenge in which they can participate.

This paper's contributions include:

1. Providing the primary overview for the 2018 edition of the track, detailing track design and motivating why core design decisions were made.
2. Providing an analysis of the distribution of information posted on social media during emergency situations, contrasting general information types against actionable information based on labelling efforts undertaken during the track.
3. Giving a high-level examination of systems that participated in the 2018 edition, highlighting state-of-the-art performance for this task and what the challenges are moving forward.

RELATED DATA CHALLENGES AND INITIATIVES

TREC-IS builds upon expertise from previous evaluation initiatives and data challenges and is part of the long-running TREC conference. TREC is a combined conference and evaluation campaign that encourages research into information retrieval technologies on large test collections. Sponsored by NIST, TREC has run annually for over 25 years and consists of a set tracks, where a track is an area of focus in which particular retrieval tasks are defined. Tracks act as incubators for new research areas, in which the first run of a track often concretizes the problem, and a track creates the necessary infrastructure (test collections, evaluation methodology, etc.) to support research on its task. The tracks also demonstrate the robustness of core retrieval technology in that the same techniques are frequently appropriate for a variety of tasks. Finally, tracks make TREC attractive to a broader community by providing tasks that match the research interests of more groups. TREC has been highly influential in the information retrieval domain, resulting in foundational research into search engines (Robertson et al. 1995) and information extraction from social media (Lin, Roegiest, et al. 2016). TREC-IS is a new TREC track[2] started in 2018 and is designed to unite academia and industry around research into automatically processing social media streams during emergency situations and categorizing information and aid requests made on social media for emergency service operators.

TREC-IS also builds on lessons learned from the Exploitation of Social Media for Emergency Relief and Preparedness (SMERP) workshop (Ghosh et al. 2017), which itself was inspired by the TREC Microblog track (Lin, Efron, et al. 2014). The 2017 SMERP workshop examined two challenges: 1) text retrieval for disaster-related queries on Twitter, 2) text summarization of tweets during a disaster event. For the text retrieval task, the challenge defined four information needs: 'what resources are available'; 'what resources are required'; 'what infrastructure damage, restoration and casualties are reported'; and 'what are the rescue activities of various NGOs / government organizations'. We integrated two main lessons from that data challenge: First, the information needs defined by

[1] https://trec.nist.gov/
[2] http://trecis.org

the SMERP challenge was quite broad, making it difficult to map an information need to an activity that might be performed by a response officer. We therefore developed our own information ontology, which we present in more detail later. Second, due to the small number of information needs and only the single event examined during the SMERP challenge, participating systems' generalizability was unclear. Hence, for TREC-IS, we opted for a larger pool of events across six different event types.

INCIDENT STREAMS TASK

2018 was the first year of the track and focused on how to produce a series of curated feeds of social media posts, where each feed corresponds to a particular type of information request, aid request, or report. Each post in these feeds was also given a criticality score, indicating how critical it was that a user be shown that post. This task is referred to as *classifying tweets by information type (high-level)*, which we define below.

Use-case: Enhanced Situational Awareness

As identified by FEMA (FEMA 2013), social media streams can support several valuable use-cases before, during and after emergency events, including: building situational awareness; understanding issues/needs/concerns from the public and survivors; and saving lives through rapid communication. To situate TREC-IS in this space, we first needed to define the use-case the track would satisfy, which would provide a better understanding of how social media could address problems a real user may have (Whipkey and Verity 2015). Based on discussions with officers from civil protection and resilience agencies, we opted for targeting increased *situational awareness*, a use-case that these stakeholders a) believed social media was suitable for and b) currently lacked the means to effectively tackle. Linking this use-case to existing information flow taxonomies during crisis scenarios (Reuter, Marx, et al. 2012), our task involves enhancing the 'citizen to authority' information flow, thereby improving the authority's situational awareness. Specifically, we consider our end-users to be public safety officers in the central command and control centre during an emergency. These users might be responsible for identifying actionable information that other officers can use to direct response efforts and/or answer questions from the public.

Task Formulation

We formally define the TREC-IS *Classifying Tweets by Information Type (high-level)* task as follows: Given a single social media post p published at time t (p_t), assign a high-level information type i (e.g. "call for help") from a set I ($i \in I$) to p_t, and provide a critically score c to p_t, where $0 \leq c \leq 1$. Higher criticality scores indicate that the post contains more important actionable information. Systems may use information that is publicly available prior to t when processing a post p_t.

Mapping this definition to our use-case, the information type (i) assigned to a post indicates the 'feed' to which the post belongs. The criticality score identifies posts that need to be shown to an officer immediately as an alert.

INFORMATION TYPE ONTOLOGY

We next define the information types I that systems may assign to a post. To identify our information types, we build upon past works that examine how to categorize emergency related content. In particular, a survey (Castillo 2016) of previous categorization efforts identified eight main dimensions of categorization, namely: by information provided/contained (Truelove et al. 2015); fact vs. subjective vs. emotional content (Kumar et al. 2013); by information source (Olteanu, Castillo, et al. 2014); by credibility (Castillo et al. 2013); by time (Chowdhury et al. 2013); by location (De Longueville et al. 2009); by embedded links (Shaw et al. 2013); or by environmental relevance (physical, built or social) (Mileti 1999). Given our use-case, our primary requirement is that information types represent categories of information that emergency response officers might be interested in, such as 'Reports of Road Blockages' or 'Calls for Help'. We therefore are mainly concerned with categorization by information provided/contained. However, in some scenarios it may also be valuable to consider categorization by information source (to help find first-hand reports) or credibility.

We also analysed incident management ontologies such as MOAC (Management of a Crisis)[3], response documentation (FEMA 2011) and discussed the challenges with experts. This provided a small number of additional information types, some of which were specific to an event type (e.g. 'Are the Assailants Armed?' for terrorist attacks). Aggregating information categories from prior research with categories derived from emergency management documentation and practitioners provides us with a granular view of what information is valuable during an emergency.

[3] http://observedchange.com/moac/ns/

High-Level Information Type	Description	Example Low Level Types
Request-GoodsServices	The user is asking for a particular service or physical good.	PsychiatricNeed, Equipment, ShelterNeeded
Request-SearchAndRescue	The user is requesting a rescue (for themselves or others)	SelfRescue, OtherRescue
Request-InformationWanted	The user is requesting information	PersonsNews, MissingPersons, EventStatus
CallToAction-Volunteer	The user is asking people to volunteer to help the response effort	RegisterNow
CallToAction-Donations	The user is asking people to donate goods/money	DonateMoney, DonateGoods
CallToAction-MovePeople	The user is asking people to leave an area or go to another area	EvacuateNow, GatherAt
Report-FirstPartyObservation	The user is giving an eye-witness account	CollapsedStructure, PeopleEvacuating
Report-ThirdPartyObservation	The user is reporting a information from someone else	CollapsedStructure, PeopleEvacuating
Report-Weather	The user is providing a weather report (current or forecast)	Current, Forecast
Report-EmergingThreats	The user is reporting a potential problem that may cause future loss of life or damage	BuildingsAtRisk, PowerOutage, Looting
Report-SignificantEventChange	The user is reporting a new occurrence that public safety officers need to respond to.	PeopleTrapped, UnexplodedBombFound
Report-MultimediaShare	The user is sharing images or video	Video, Images, Map
Report-ServiceAvailable	The user is reporting that someone is providing a service	HospitalOperating, ShelterOffered
Report-Factoid	The user is relating some facts, typically numerical	LandDevastated, InjuriesCount, KilledCount
Report-Official	An official report by a government or public safety representative	OfficialStatement, RegionalWarning, PublicAlert
Report-CleanUp	A report of the clean up after the event	CleanUpAction
Report-Hashtags	Reporting which hashtags correspond to each event	SuggestHashtags
Other-PastNews	The post is generic news, e.g. reporting that the event occurred	NewsHeadline
Other-ContinuingNews	The post providing/linking to continuous coverage of the event	NewsHeadline, SelfPromotion
Other-Advice	The author is providing some advice to the public	SuggestBestPractices, CallHotline
Other-Sentiment	The post is expressing some sentiment about the event	Sadness, Hope, Wellwishing
Other-Discussion	Users are discussing the event	Causes, Blame, Rumors
Other-Irrelevant	The post is irrelevant, contains no information	Irrelevant
Other-Unknown	Does not fit into any other category	Unknown
Other-KnownAlready	The Responder already knows this information	KnownAlready

Table 1. Ontology High-level Information Types

Such valuable information is rare on social media, as most information shared during emergencies is of lower importance, such as news reports or shocking images. On the other hand, these other types of information may be valuable to researchers studying emergencies in the future when tackling other use-cases. Moreover, providing more resolution on what is likely 'non-relevant' for our use-case may help systems avoid miss-categorizing that content. We then expanded our initial set of information types via a bottom-up analysis of Twitter content from a small sample of events. This resulted in additional information types such as 'Sentiment Expressed', 'Press Releases' and 'Sharing Best Practices'.

In this way, we created a broad ontology of over 100 information types that are either important to emergency response officers or are commonly shared during events.[4] For the purposes of the track, asking participants to categorize posts into over 100 distinct types is unreasonable for the first year of the track. We instead grouped the individual low-level ontology entries into higher-level types. For example, we merged low level entries such as 'Hospital Operating', 'Shelter Offered' and 'Food Distribution Point' into the higher-level type 'Service Available'. In total, we defined 25 high-level types, as shown in Table 1, which form our information type categories I.

DATASET CREATION

A core component of TREC-IS is a set of evaluation datasets. A dataset is comprised of two components: a series of topics, each representing an emergency event; and the social media posts for each of those events. We summarize the creation of these below.

Twitter as a Data Source

The field of social media for emergency management is broad (Palen and Liu 2007; Hughes and Palen 2009; Middleton et al. 2014) in that a wide variety of data types and sources exist that we might desire to analyze. The majority of prior research into social media during emergencies, however, has focused on Twitter data (Reuter, Backfried, et al. 2018), likely due to ease of access. As a new initiative that aims to bring together researchers already working in the field, for the first year of TREC-IS we maintain this trend by using Twitter data, although we are interested in additional sources in future years.

Topics/Events

Our goal is to provide a sound, reproducible experimental environment, where researchers and practitioners can evaluate systems for the TREC-IS task. While most studies in this context have focused on small numbers of events, this choice is problematic; while interesting observations can be made on such datasets, we cannot show how systems generalize across events of the same type or across types. Moreover, with small datasets, illustrating statistically significant differences between systems becomes challenging. Hence, we need to create a dataset that

[4]An early visualization of the ontology can be seen at http://trecis.org/WebVOWL/#trecis

Dataset	Identifier	Event Name	Event Type	Source
Training	TRECIS-CTIT-H-Training-001	2012 Colorado wildfires	wildfire	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Training-002	2012 Costa Rica Earthquake	earthquake	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Training-003	2013 Colorado Floods	flood	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Training-004	2012 Typhoon Pablo	typhoon/hurricane	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Training-005	2013 LA Airport Shooting	shooting	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Training-006	2013 West Texas Explosion	bombing	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
Test	TRECIS-CTIT-H-Test-007	2012 Guatemala earthquake	earthquake	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-008	2012 Italy earthquakes	earthquake	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-009	2012 Philipinnes floods	flood	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-010	2013 Alberta floods	flood	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-011	2013 Australia bushfire	wildfire	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-012	2013 Boston bombings	bombing	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-013	2013 Manila floods	flood	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-014	2013 Queensland floods	flood	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-015	2013 Typhoon Yolanda	typhoon	CrisisLexT26 (Olteanu, Vieweg, et al. 2015)
	TRECIS-CTIT-H-Test-016	2011 Joplin tornado	typhoon	CrisisNLP Resource #2 (Imran, Elbassuoni, et al. 2013b)
	TRECIS-CTIT-H-Test-017	2014 Chile Earthquake	earthquake	CrisisNLP Resource #1 (Imran, Mitra, et al. 2016)
	TRECIS-CTIT-H-Test-018	2014 Typhoon Hagupit	typhoon	CrisisNLP Resource #1 (Imran, Mitra, et al. 2016)
	TRECIS-CTIT-H-Test-019	2015 Nepal Earthquake	earthquake	CrisisNLP Resource #1 (Imran, Mitra, et al. 2016)
	TRECIS-CTIT-H-Test-020	2018 FL School Shooting	shooting	Crawled by the Organizers via Twitter API
	TRECIS-CTIT-H-Test-021	2015 Paris attacks	bombing	Collected via the GNIP service

Table 2. TREC-IS 2018 Training and Test Events

covers a sufficient number of events for performance patterns to become identifiable. Furthermore, state-of-the-art approaches in information categorization for emergency-related content involve training supervised machine learned models, which need training examples to learn. To ensure a realistic evaluation of these models, we create two datasets, one for training such models and one for testing those models.

As a track, we are interested in emergency events, either natural or man-made. Furthermore, we anticipated that effective systems for the task may require customization for different types of event (McCreadie et al. 2018). For example, there is no point in looking for tweets with information about 'Are the Assailants Armed?' during earthquakes. For this reason, we first selected a small set of six event types to target rather than considering any event type:

Wildfire, Earthquake, Flood, Typhoon/Hurricane, Bombing, Shooting

Given these event types, we needed to decide what events to use. In a real deployment of an information-type categorization system for social media content, one would need to tackle irrelevant or off-topic content within the stream (e.g. due to imperfect data collection (Saleem et al. 2014)). For the first year of the track, we simplified the task and use only on-topic data. For this reason, we collected existing event datasets shared by other emergency management initiatives that had already been manually filtered for relevance. We then combined those datasets together to form the training and test datasets for TREC-IS 2018. In particular, we collected 19 events across the CrisisLex (Olteanu, Vieweg, et al. 2015) and CrisisNLP (Imran, Mitra, et al. 2016) initiatives. We also crawled two additional datasets ourselves for the purposes of comparison. The resultant 21 events and their sources are summarized in Table 2, the first 6 of which form the training dataset, while the latter 15 events form the test dataset.

Datasets From Social Media Streams

Data Collection: For the events listed in Table 3, we provide a stream of tweet statuses (JSON format) collected during that event for download. For the 19 events derived from either CrisisLex or CrisisNLP, we first independently crawled the tweets listed in those datasets by their unique identifier using the Twitter Streaming API . For TRECIS-CTIT-H-Test-020 (a contemporary event from 2018), we also used the Twitter Streaming API to crawl the event while as it occurred. Meanwhile, for TRECIS-CTIT-H-Test-021 we retrospectively collected unique tweets using the GNIP service .

Filtering: To reduce the barrier to entry for the first year, we desired a relevant-only set of tweets for systems to process. For the CrisisLex and CrisisNLP datasets, we pre-filtered using the human annotation labels provided, removing tweets marked with labels such as 'Not Related' or 'Not Relevant'. For the two events collected by the organizers (TRECIS-CTIT-H-Test-020 and TRECIS-CTIT-H-Test-021), we lacked human-generated relevance labels and instead performed KMeans clustering for each event. Each event was clustered into 10k clusters based on textual similarity, and we selected one tweet per cluster (the centroid tweet) to be subsequently labelled. For these two events, due to their size, we also performed additional manual keyword filtering (using terms extracted from an associated Wikipedia page for each event) to reduce it to a diverse and relevant set. We also removed non-English tweets for all events. The statistics of the tweet streams for each event are shown in Table 3.

Dataset	Identifier	Event Name	# Posts Pre-Filtering	# Posts Post-Filtering
Training	TRECIS-CTIT-H-Training-001	2012 Colorado wildfires	3,275	744
	TRECIS-CTIT-H-Training-002	2012 Costa Rica Earthquake	1,880	288
	TRECIS-CTIT-H-Training-003	2013 Colorado Floods	1404	777
	TRECIS-CTIT-H-Training-004	2012 Typhoon Pablo	1,413	649
	TRECIS-CTIT-H-Training-005	2013 LA Airport Shooting	2031	683
	TRECIS-CTIT-H-Training-006	2013 West Texas Explosion	9,877	630
Test	TRECIS-CTIT-H-Test-007	2012 Guatemala earthquake	2,518	178
	TRECIS-CTIT-H-Test-008	2012 Italy earthquakes	5,740	118
	TRECIS-CTIT-H-Test-009	2012 Philipinnes floods	1,658	480
	TRECIS-CTIT-H-Test-010	2013 Alberta floods	4,559	739
	TRECIS-CTIT-H-Test-011	2013 Australia bushfire	1,507	710
	TRECIS-CTIT-H-Test-012	2013 Boston bombings	98,884	543
	TRECIS-CTIT-H-Test-013	2013 Manila floods	1,289	443
	TRECIS-CTIT-H-Test-014	2013 Queensland floods	832	744
	TRECIS-CTIT-H-Test-015	2013 Typhoon Yolanda	27,755	629
	TRECIS-CTIT-H-Test-016	2011 Joplin tornado	206,764	152
	TRECIS-CTIT-H-Test-017	2014 Chile Earthquake	368,630	321
	TRECIS-CTIT-H-Test-018	2014 Typhoon Hagupit	625,976	6,696
	TRECIS-CTIT-H-Test-019	2015 Nepal Earthquake	4,223,937	7,301
	TRECIS-CTIT-H-Test-020	2018 FL School Shooting	12,082,953	1,118
	TRECIS-CTIT-H-Test-021	2015 Paris attacks	1,671,440	2,066

Table 3. TREC-IS 2018 Stream Statistics

LABELING TWEETS WITH INFORMATION TYPES AND PRIORITIES

To evaluate systems' performance, we required ground truth information-type and criticality labels for training and test sets. A team of TREC assessors created this ground truth by reviewing each event and hand-labeling tweets in that event, one tweet per assessor, using the assessment interface shown in Figure 1. These TREC assessors were experienced information generalists with a strong analytical background. For labeling tasks, NIST trains assessors using sample materials and works closely with them to ensure label quality and consistency.

Tweets from the 15 test events were labelled by TREC Assessors during August 2018. TREC assessors were contracted for this assessment and brought into a controlled lab environment for the duration of the job. Six TREC assessors contributed to the labelling of the events. Assessors were trained in following the ontology and identifying critical tweets using the 2012 Colorado, US wildfires event. As a group, the assessment team labeled tweets in the training event and discussed how to make decisions for confusing or ambiguous cases. Furthermore, each event type was accompanied by an information sheet defining the critical types of information expected during an event of that type. This information sheet was also provided to TREC-IS participants in the form of user profiles for each event type.

Two events were large (2014 Typhoon Hagupit and 2015 Nepal Earthquake) and were divided among multiple assessors (the partitions are denoted *DATASET*S1, *DATASET*S2, etc.). Labelling statistics divided by assessor and event are provided in Table 4. Note that as the assessment interface performed automatic textual de-duplication of tweets, the number assessed is lower than the number of tweets in each dataset.

One interesting factor to consider about this labelling task is that it involves markedly more effort by the assessors than a classical tweet categorization task, as can be seen by the high average time spent assessing each tweet across assessors (see column 4 in Table 4). This effort results from the assessors not only reading the text of each tweet but also examining linked content (e.g. news articles) and any attached videos. The level of effort required in labeling prevented a balanced study of agreement. Across the six TREC assessors, the track's test dataset contains 19,784 labeled tweets with 43,514 category labels.

METRICS

Participating organizations could submit up to four *runs*. Each submitted run gives a predicted information type and criticality score to each tweet. Participant runs are evaluated against two criteria: 1) how well did they identify the information type of the tweet (Information Type Categorization); and 2) how accurately did they estimate the criticality of the information within each tweet (Information Criticality).

Information Type Categorization

The first evaluation axis for a TREC-IS system is how effectively it can categorize tweets into the 25 high-level information types in the TREC-IS Ontology. Notably, participant systems for 2018 were tasked with assigning one

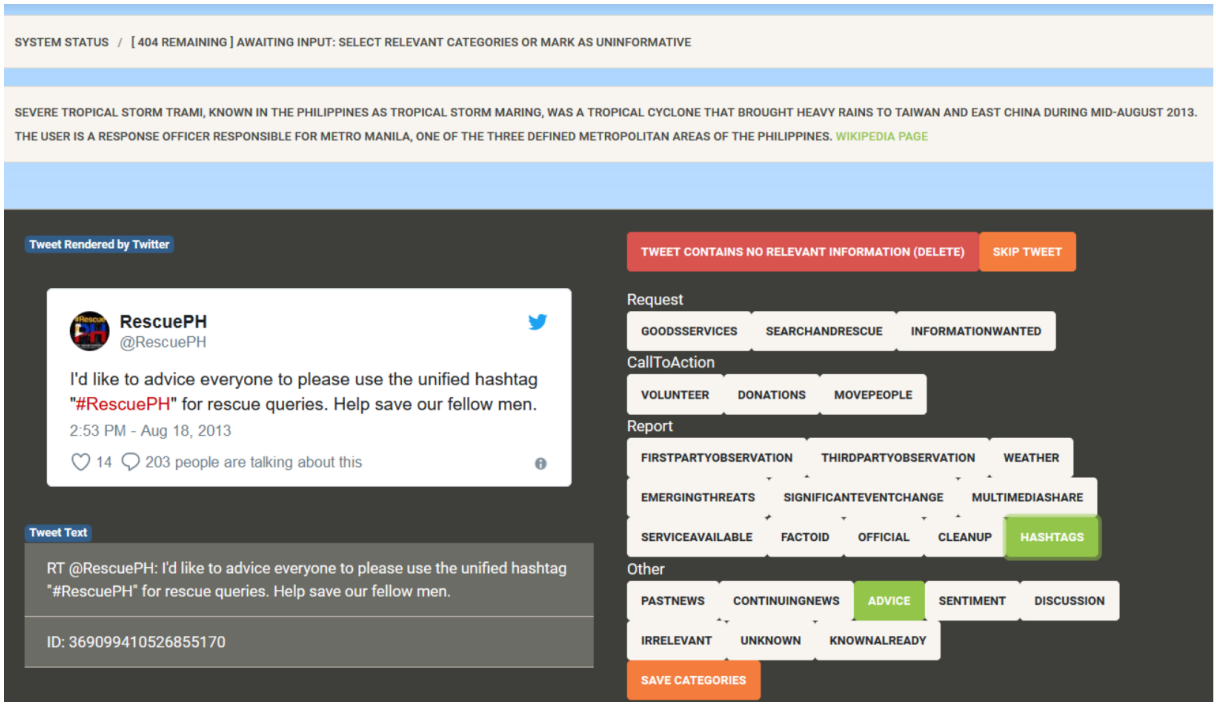


Figure 1. TREC-IS Task Assessment Interface

information type per-tweet (the most representative one). When creating the ground truth, however, TREC assessors were allowed to select multiple information types. For this reason, we evaluate information type categorization in two ways: multi-type and any-type.[5]

- **Multi-Type**: Under multi-type evaluation, we calculate categorization performance per information type in a 1-vs-All manner. A system is considered to have categorized a tweet correctly if both the system and human assessor selected that category. Note that since a system can only select one category per tweet but the assessors can select multiple categories per tweet, system performance across information types cannot be perfect under this metric. For instance, if a tweet had three information types assigned to it by the human assessor, then a system can only receive a maximum of a 1/3 score for that tweet. Multi-type evaluation is primarily useful for contrasting performance between information types or between events. We evaluate multi-type classification performance under four metrics: Precision/Recall/F1 (Positive Class) and Accuracy (Overall).
- **Any-Type**: Under any-type evaluation, a system receives a full score for a tweet if the system assigned any of the categories that the human assessor selected for that tweet. This metric provides absolute classification performance of a TREC-IS system but is more heavily influenced by larger events and more common information types (which may be less valuable for our end-users). For Any-Type, we report Precision/Recall/F1 (micro averaged) and Accuracy (micro averaged).

Information Criticality

The second axis of evaluation for a TREC-IS system is the extent to which it can identify key information that emergency response officer needs to see. This evaluation is operationalized by comparing a tweet's information priority score provided by a system to the criticality label provided by the human assessor.

To enable this comparison, two transformations were first performed. First, four information criticality labels used by the human assessors were mapped into numerical scores as per the guidelines. In this case, low=0.25, medium=0.5, high=0.75 and critical=1.0. Second, as some participant systems did not provide scores within a 0-1 range, all system scores were subject to a max-min normalization, with a minimum score cap of 0.25. Criticality estimation performance was then measured in terms of the *Mean Squared Error* between the human assigned score and the normalized system criticality score (lower is better).

[5]See http://trecis.org/2018/Evaluation.html for details.

Assessor ID	Event Name	Dataset ID	Time Per Tweet (seconds)	# Tweets Labelled
assr1	2012 Guatemala earthquake	guatemalaEarthquake2012	81	137
	2013 Boston bombings	bostonBombings2013	65	488
	2018 FL School Shooting	flSchoolShooting2018	59	1032
assr2	2014 Chile Earthquake	chileEarthquake2014	60	286
	2011 Joplin tornado	joplinTornado2011	41	94
	2013 Typhoon Yolanda	typhoonYolanda2013	45	538
	2013 Queensland floods	queenslandFloods2013	35	689
	2015 Nepal Earthquake	nepalEarthquake2015S3	25	1377
assr3	2013 Australia bushfire	australiaBushfire2013	30	664
	2012 Philipinnes floods	philipinnesFloods2012	24	434
	2013 Alberta floods	albertaFloods2013	24	717
	2015 Nepal Earthquake	nepalEarthquake2015	27	128
	2015 Nepal Earthquake	nepalEarthquake2015S2	23	1393
	2014 Typhoon Hagupit	typhoonHagupit2014S2	22	1346
assr4	2013 Manila floods	manilaFloods2013	23	404
	2015 Paris attacks	parisAttacks2015	16	2037
	2012 Italy earthquakes	italyEarthquakes2012	18	100
assr5	2014 Typhoon Hagupit	typhoonHagupit2014	48	1381
	2014 Typhoon Hagupit	typhoonHagupit2014S1	39	1302
assr6	2015 Nepal Earthquake	nepalEarthquake2015	30	1881
	2015 Nepal Earthquake	nepalEarthquake2015S1	23	1389
	2015 Nepal Earthquake	nepalEarthquake2015S4	19	1392

Table 4. Event Labelling Statistics for the Test Events (TRECIS-CTIT-H 2018 Test).

ANALYSING ASSESSOR AND PARTICIPANT RESULTS

After collecting information-type and criticality labels from assessors and track participants, we investigate two groups of research questions regarding information posted on social media and TREC-IS participants' performance in the track. First, questions that relate specifically to the 19,784 unique tweets labeled by our assessors:

- **RQ1.1** How common are different types of information posted to Twitter during emergencies?
- **RQ1.2** How prevalent is critical/actionable information on Twitter?

Second, by analysing the performance of the 39 systems submitted to the 2018 track we investigate the following:

- **RQ2.1** How well can systems identify different information types?
- **RQ2.2** Are specific information types generally more difficult to identify?
- **RQ2.3** How well do systems perform at information criticality classification?

RQ1.1: How Prevalent is Information on Twitter during Emergencies?

The first question concerns how common different information types are on Twitter based on the TREC-IS test dataset (15 events). This statistic is valuable as it provides insights on how much actionable information one may find on social media.[6] To contrast general and actionable information, for our analysis in this section, we consider the following types of information as actionable: Requests for Goods/Services, Requests for Search and Rescue, Calls to Action for Moving People (Evaluations), Reports of Emerging Threats, Reports of Significant Event Changes and Reports of Services becoming available. This definition of actionability differs from works like (Zade et al. 2018) as it is information type-based. We assume an "actionable" post that generates an immediate alert will be useful to an individual responsible for that type (optionally considering criticality as well). Table 5 reports the number of tweets labeled with each of the 25 information types in the test dataset. Our expectation is that distributions of information types will differ across event types, so we divide these counts across our six event types. The percentage reported after each count is the proportion of tweets for that information type and event type.

[6]Note this is subject to both the sampling strategies employed by the CrisisLex and CrisisNLP original sources and the subsequent filtering we applied.

High-Level Information Type	Wildfire	Earthquake	Flood	Typhoon/Hurricane	Bombing	Shooting
Request-GoodsServices	0 (0%)	72 (0.49%)	48 (0.87%)	5 (0.04%)	1 (0.02%)	0 (0%)
Request-SearchAndRescue	0 (0%)	177 (1.2%)	110 (2%)	6 (0.05%)	5 (0.09%)	0 (0%)
Request-InformationWanted	1 (0.05%)	99 (0.67%)	25 (0.45%)	42 (0.32%)	6 (0.11%)	1 (0.03%)
CallToAction-Volunteer	1 (0.05%)	25 (0.17%)	49 (0.89%)	33 (0.26%)	4 (0.08%)	4 (0.12%)
CallToAction-Donations	15 (0.81%)	424 (2.88%)	173 (3.14%)	160 (1.24%)	9 (0.17%)	15 (0.47%)
CallToAction-MovePeople	1 (0.05%)	5 (0.03%)	11 (0.2%)	8 (0.06%)	0 (0%)	0 (0%)
Report-FirstPartyObservation	102 (5.51%)	1432 (9.74%)	743 (13.5%)	1330 (10.29%)	75 (1.41%)	2 (0.06%)
Report-ThirdPartyObservation	529 (28.58%)	481 (3.27%)	560 (10.17%)	1992 (15.41%)	618 (11.64%)	9 (0.28%)
Report-Weather	7 (0.38%)	31 (0.21%)	66 (1.2%)	1232 (9.53%)	0 (0%)	0 (0%)
Report-EmergingThreats	22 (1.19%)	332 (2.26%)	110 (2%)	113 (0.87%)	86 (1.62%)	33 (1.02%)
Report-SignificantEventChange	25 (1.35%)	85 (0.58%)	72 (1.31%)	74 (0.57%)	161 (3.03%)	0 (0%)
Report-MultimediaShare	99 (5.35%)	1287 (8.76%)	413 (7.5%)	1237 (9.57%)	367 (6.91%)	550 (17.06%)
Report-ServiceAvailable	29 (1.57%)	794 (5.4%)	61 (1.11%)	152 (1.18%)	76 (1.43%)	0 (0%)
Report-Factoid	227 (12.26%)	922 (6.27%)	126 (2.29%)	807 (6.24%)	212 (3.99%)	68 (2.11%)
Report-Official	73 (3.94%)	85 (0.58%)	151 (2.74%)	91 (0.7%)	7 (0.13%)	0 (0%)
Report-CleanUp	0 (0%)	14 (0.1%)	23 (0.42%)	21 (0.16%)	0 (0%)	1 (0.03%)
Report-Hashtags	0 (0%)	631 (4.29%)	488 (8.86%)	1205 (9.32%)	759 (14.29%)	174 (5.4%)
Other-PastNews	2 (0.11%)	83 (0.56%)	41 (0.74%)	23 (0.18%)	255 (4.8%)	946 (29.34%)
Other-ContinuingNews	435 (23.5%)	1440 (9.8%)	840 (15.26%)	1790 (13.85%)	424 (7.98%)	106 (3.29%)
Other-Advice	65 (3.51%)	396 (2.69%)	459 (8.34%)	242 (1.87%)	32 (0.6%)	3 (0.09%)
Other-Sentiment	177 (9.56%)	3326 (22.63%)	501 (9.1%)	1584 (12.26%)	1043 (19.64%)	234 (7.26%)
Other-Discussion	1 (0.05%)	941 (6.4%)	24 (0.44%)	302 (2.34%)	213 (4.01%)	709 (21.99%)
Other-Irrelevant	39 (2.11%)	1192 (8.11%)	379 (6.88%)	341 (2.64%)	652 (12.28%)	86 (2.67%)
Other-Unknown	0 (0%)	53 (0.36%)	12 (0.22%)	9 (0.07%)	4 (0.08%)	0 (0%)
Other-KnownAlready	1 (0.05%)	372 (2.53%)	20 (0.36%)	126 (0.97%)	301 (5.67%)	283 (8.78%)

Table 5. Prevalence of High-level Information Types across Event Types. Information Types highlighted in bold are those we consider 'actionable'.

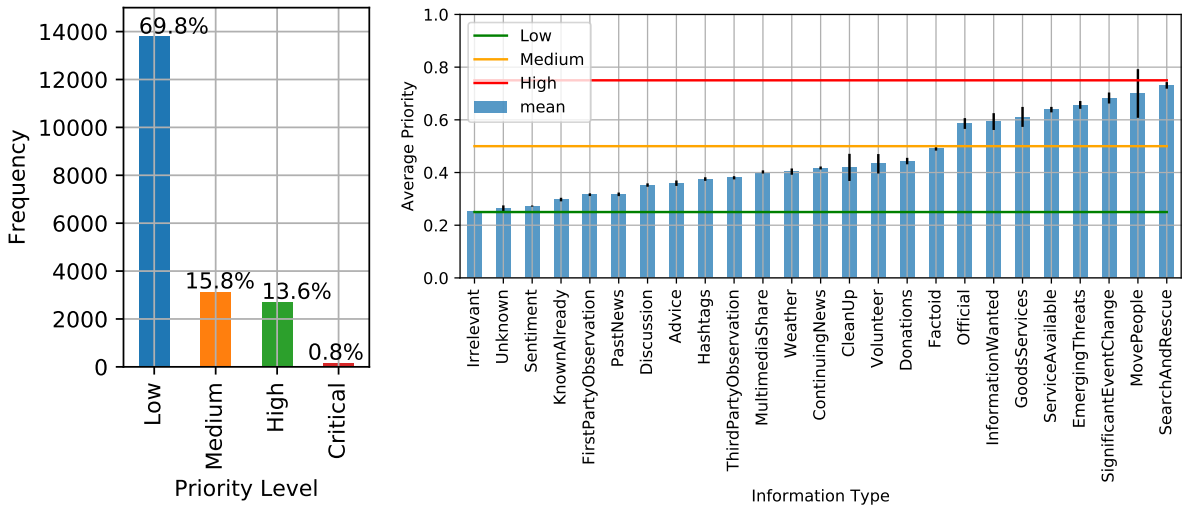
Table 5 shows the following interesting trends: For Wildfire events, the main types of information reported in Twitter are Third Party Observations (29%), Factoids (12%, typically the amount of area destroyed) and News reports (24%). Restricting to actionable information types totals around 4%, which is almost all reports. For Earthquake events, we see a more even spread of information types. The most prevalent information type is Sentiment (23%), with First Party Observations (10%) and Multimedia Sharing (9%) also being popular. In terms of actionable information, this event type has the largest proportion of reports of Services becoming Available again (1.2%) and has the highest proportion of actionable information overall (10%). For Flooding events, First Party Observations (14%), Third Party Observations (10%) and News Reports (16%) are the most common. Meanwhile, this event type has the highest proportion of requests for Search and Rescue (2%), with around 7% of the tweets belonging to our 'actionable' information types. During Typhoon/Hurricane events, we again see a high prevalence of First Party Observations (10%) and Third Party Observations (14%), with Multimedia Sharing (10%), News Reporting (14%) and expressing Sentiment (12%) also being popular. The amount of actionable information here appears to be lower, with very few requests for aid, and only around 2.5% of posts containing potentially valuable reports. Moving to the man-made emergency event types, for Bombings, Third Party Observations (12%) and Sentiment (20%) are the most common information types. Around 6% of tweets contain potentially actionable information, which is almost exclusively reports rather than requests for aid. Finally, for the shooting event (only one exists in the test dataset), we see a markedly different distribution of information types: The most common are Multimedia Sharing (17%), Past News (29%, analysing the shooter's history) and related discussions (22%, about gun control in the U.S.). Almost no actionable information exists on social media during this event (1%).

In conclusion, we can see marked differences between the information types that are prevalent during different types of events. However, in terms of potentially actionable information from the perspective of a response officer, there appears to be valuable information here that can be accessed, with up-to 10% of the tweets containing actionable information according to our definition (although some of that information may be redundant).

RQ1.2: How Much Information is Critical?

Having examined the information type distribution within our test dataset from the perspective of types that we might consider actionable, we next contrast this result against what our assessors judged to be critical information. Recall that for each tweet, our assessors assigned a criticality label (Critical, High, Medium or Low) to each tweet, which we then mapped into a criticality score (Critical=1.0, High=0.75, Medium=0.5 and Low=0.25). In this section we examine the distribution of criticality among the tweets in the test dataset.

We first averaged the criticality scores for all 15 test events, resulting in an average tweet criticality of $\mu = 0.3632$, with a standard deviation $\sigma = 0.1880$. This result suggests, as we might expect, the majority of crisis-related



(a) Criticality Distribution **(b) Average Criticality by Information Type (95% Confidence)**

Figure 2. Criticality Distributions Across and Within Information Types

tweets are between low and medium criticality. Figure 2a shows number of tweets assessed for each criticality level, while 2b reports criticality by information-type. Figure 2a shows the majority of tweets are of Low and Medium criticality (69.8% and 15.8%, respectively), i.e. a response officer would not need to see these tweets. However, we do see a relatively large proportion (14.4%) of tweets our assessors judged as important for a response officer to see promptly. Examples include pictures and videos taken during the emergency or status updates from the ground. For instance, during Typhoon Hagupit, the tweet *"Borongan, Eastern Samar's communication lines and power & water lines are still down. /via @EdwinSevidal #RubyPH"* was judged as having a high priority. Furthermore, while the proportion is small (0.8%), we also see tweets that are critical for an emergency response officer to see (and act on) immediately. These are often timely updates on potentially life-threatening impacts. For example, during Typhoon Hagupit again, the tweet *"Typhoon Hagupit hit Eastern Samar. ACTalliance local partners see transitionsal shelters blown away. Need to assess damage and respond asap"* was judged as critical. This result shows important information gets transmitted via social media during crises, supporting the idea that emergency response agencies should consider it a primary communication channel.

RQ2.1: Can Systems Effectively Identify Information Types?

Having analysed information type labels, we next examine whether current systems can automatically identify these types. Since TREC-IS's overall goal is to advance the TRL of current (automated) social media crisis monitoring solutions, rather than to study how humans annotate social media data, remaining sections focus on systems participating in TREC-IS 2018. Eleven research groups from eight countries participated in this track in 2018, submitting a total of 39 runs (each representing a different implementation).

The first question we examine is to what extent these systems able to automatically identify the 25 information categories. Table 6 reports system performance, ranked by the Any-Type, Micro Avg F1 metric (best score under each metric is highlighted in bold). Our analysis focuses on the Multi-Type metrics, as they provide more insights into categorization performance.

Multi-Type metrics have two sub-types: *Positive Class*, or how effectively a system classifies each information type in a one-versus-all manner; and *Overall*, that calculates (overall) classification accuracy. To perform well under the Multi-Type Positive Class metrics, a system needs to be effective at identifying tweets that belong to each information type (we only consider true positives and true negatives here). Moreover, it needs to perform well for the majority of the information types, as we uniformly average across information types. In contrast, Overall (Accuracy) also considers when a system correctly did not assign a category.[7] Table 6 shows that under the Multi-Type Positive Class metrics, performance is low across all 39 systems, with F1 scores ranging from 4% (lowest) to 15.7% (highest). One should recall this estimate underestimates the true performance of these systems, as systems only assigned a single type per tweet, while the assessors could assign multiple types. Even

[7]Most tweets belong to one or two categories, meaning that true negatives are vastly more common than true positives, hence Overall scores will be much higher than Positive Class scores.

Run	Information Type Categorization								Information Criticality
	Multi-Type, Macro Avg.				Any-Type, Micro Avg.				
	Positive Class			Overall	Precision	Recall	F1	Accuracy	Mean Squared Error
	Precision	Recall	F1	Accuracy			(Target Metric)		(Lower is better)
cbnuS2	**0.2666**	0.1122	0.1262	**0.9059**	0.4559	0.7780	**0.5749**	**0.4213**	0.0943
KDEIS4_DM	0.1483	0.0708	0.0734	0.9035	0.3914	0.9856	0.5603	0.3908	0.0841
umdhcilfasttext	0.1827	0.0962	0.1117	0.9044	0.4534	0.7260	0.5582	0.4022	0.0943
cbnuS1	0.2187	0.1164	0.1254	0.9048	0.4472	0.7402	0.5575	0.4064	0.0943
NHK_run2	0.2104	0.1005	0.1187	0.9042	0.4483	0.7143	0.5509	0.3997	0.0623
DLR_Simple_CNN	0.2446	0.1676	0.1595	0.9036	0.4220	0.7749	0.5464	0.3919	0.1640
NHK_run3	0.2302	0.0952	0.1140	0.9042	0.4701	0.6405	0.5422	0.3996	0.0611
cbnuC2	0.2313	0.1025	0.1164	0.9034	**0.5320**	0.5335	0.5327	0.3893	0.0943
DLR_Baseline	0.1502	0.0710	0.0743	0.9033	0.4813	0.5778	0.5251	0.3881	0.1493
SINAI_run1	0.1729	0.0726	0.0787	0.9030	0.5065	0.5303	0.5181	0.3844	0.0902
SINAI_run3	0.1825	0.0713	0.0767	0.9023	0.5019	0.5130	0.5074	0.3762	0.0894
SINAI_run4	0.1782	0.0754	0.0825	0.9025	0.5297	0.4849	0.5063	0.3786	0.0926
NHK_run1	0.1940	0.1027	0.1196	0.9006	0.4063	0.6414	0.4974	0.3551	**0.0602**
cbnuC1	0.2391	0.1022	0.1152	0.9006	0.5056	0.4797	0.4923	0.3545	0.0943
myrun-10	0.1446	0.0647	0.0673	0.9005	0.4415	0.5502	0.4899	0.3533	0.0944
myrun-11	0.1625	0.0645	0.0672	0.9004	0.4401	0.5502	0.4890	0.3525	0.0941
DLR_Fusion	0.2496	**0.1664**	0.1562	0.8996	0.3811	0.6821	0.4890	0.3425	0.1594
umdhcilbaseline	0.1866	0.0906	0.1096	0.8993	0.3978	0.6251	0.4862	0.3385	0.0943
DLR_Augmented	0.2580	0.1657	**0.1571**	0.8996	0.3965	0.6165	0.4826	0.3419	0.1599
uogTr_R3_asp	0.2159	0.0945	0.1050	0.8973	0.3136	**1.000**	0.4775	0.3136	0.0916
NHK_run4	0.2073	0.0784	0.0878	0.9001	0.4729	0.4575	0.4651	0.3482	0.0663
SINAI_run2	0.1307	0.0697	0.0769	0.8988	0.4189	0.4980	0.4551	0.3317	0.0859
myrun-21	0.1496	0.0712	0.0873	0.8964	0.3514	0.6064	0.4449	0.3018	0.0958
myrun-2	0.1401	0.0674	0.0819	0.8952	0.3339	0.6004	0.4291	0.2876	0.1004
uogTr_R1_asp	0.2295	0.0823	0.0792	0.8963	0.3874	0.4578	0.4196	0.3011	0.0933
KDEIS3_ACSBLSTM	0.1209	0.0577	0.0483	0.8933	0.2631	0.9788	0.4147	0.2635	0.0842
IITBHU1	0.2522	0.1299	0.1369	0.8947	0.4264	0.3926	0.4088	0.2811	0.1244
IITBHU12	0.2522	0.1299	0.1369	0.8947	0.4264	0.3926	0.4088	0.2811	0.1244
KDEIS1_CLSTM	0.1388	0.0607	0.0620	0.8929	0.2575	0.9783	0.4078	0.2580	0.0842
umdhcilfts	0.0993	0.0499	0.0420	0.8932	0.2770	0.7566	0.4055	0.2621	0.0943
umdhcilspread	0.1289	0.0597	0.0663	0.8931	0.2764	0.7124	0.3982	0.2608	0.0943
uogTr_R2_asp	0.2313	0.0970	0.1109	0.8951	0.3623	0.4355	0.3956	0.2861	0.0931
UPB_DICE2	0.0875	0.0406	0.0421	0.8906	0.2348	0.8682	0.3696	0.2299	0.0925
UPB_DICE1	0.1827	0.0721	0.0635	0.8905	0.2713	0.5696	0.3676	0.2286	0.0916
KDEIS2_ACBLSTM	0.1512	0.0689	0.0703	0.8890	0.2089	0.9734	0.3440	0.2098	0.0842
UPB_DICE4	0.0759	0.0403	0.0406	0.8885	0.2155	0.6208	0.3200	0.2031	0.0876
myrun2_fixed	0.2076	0.0829	0.0870	0.8881	0.2076	0.5957	0.3079	0.1986	0.0793
myrun1_fixed	0.2077	0.0826	0.0809	0.8866	0.1810	0.8881	0.3007	0.1790	0.0728
UPB_DICE3	0.0926	0.0403	0.0419	0.8867	0.1949	0.4156	0.2653	0.1804	0.0942
TREC Median	0.1827	0.0784	0.0825	0.8993	0.3978	0.6165	0.4775	0.3385	0.0933

Table 6. TREC-IS 2018 Participant Run Performances.

accounting for this difference, the low performance of these systems indicates they are not yet sufficiently effective at discriminating information types. This result motivates the need for a concerted effort to bring performance up to a level that is deployable by end-users. While performance seems better when examining Overall accuracy, this increase is a reflection of the high frequency of true negatives. Potential users primarily care about getting the true positives correct (e.g., having systems that can correctly identify that urgent request for search and rescue). Hence, in summary, participant systems are getting between 85-90% of categorization decisions correct under the one-versus-all scheme, but the remaining 10-15% are often the cases that our end-users actually care about. It is thus fair to conclude that this technology is currently insufficient for deployment in practice.

RQ2.2: What Information Types are Difficult to Identify?

Insights on where current state-of-the-art systems tend to succeed or fail is important for focusing future research. While a deep analysis of individual systems is beyond this paper's scope, we perform a meta-analysis of systems by information type. In particular, we identify the best performing system for each information type and plot those best per-information type performances. This meta-analysis represents the performance distribution if we could combine all of the best-performing aspects of participant systems into a single '(beyond) state-of-the-art system'. This is informative, as we can observe gaps where participating systems performed poorly, identifying areas where the most effort is needed.

Figure 3 shows the best participant system's performance when ranked by Multi-Type, Macro Avg. Positive Class per information type under the Positive Class metrics. Across information types, the average F1 score is 0.2953, with precision 0.4151 and recall 0.3167, representing a large and statistically significant improvement over the

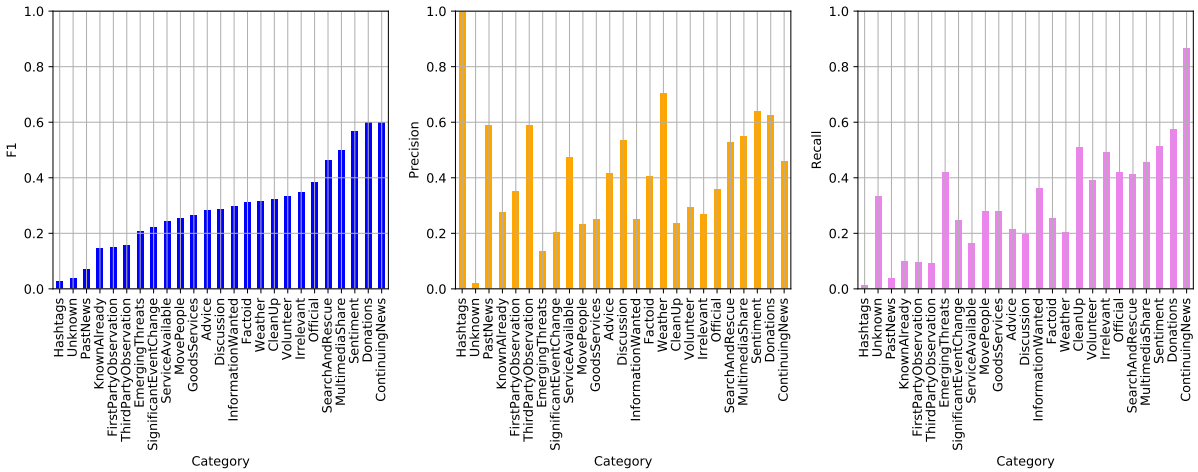


Figure 3. F1, Precision, and Recall for Best Performing Systems by Information Type

0.1571 F1 previously observed for the best single system in Table 6. While this gain is expected, the magnitude of this difference suggests high variance exists in performance among systems for each information type.

Furthermore, from Figure 3, we see the best performing systems are quite effective at identifying continuing news, donations, and expressions of sentiment. Alternatively, of the six actionable information types, all but the search-and-rescue type are in the bottom half of this ranking, suggesting even the best participant systems have difficulty with identifying this important information. We also note a weak correlation exists between the per-type F1 scores and the amount of training data made available for this edition of the track (the training dataset), which accounts for 29% of variation in scores. Given the rarity of critical information in social media data, this result reinforces the necessity of a large-scale and standardized dataset of emergency-related content. Indeed, this gap is a motivation for a continuing initiative that produces datasets with increasing size.

RQ2.3: Are Systems able to Accurately Estimate Information Criticality?

Having examined system performance for information type categorization, we next examine efficacy of criticality assessment. We measure this performance by comparing the (normalized) criticality score provided by a system for a tweet against the criticality label assigned by the assessor for that tweet. The smaller this difference (the lower the error) the better. The final column in Table 6 reports this estimation error for each system, while Figure 4 reports the average criticality scores for each system.

We make the following observations: First, Table 6 shows a more positive picture than when examining information type categorization performance, with prediction errors ranging from 0.06 to 0.16, a fairly low level of error.[8] Second, when examining systems' criticality scores, we see a markedly higher average ($\mu = 0.6067$, $\sigma = 0.2193$) than the assessors criticality scores ($\mu = 0.3632$). This result suggests participating systems tend to over-estimate the priority of messages rather than under-estimate criticality. This over-estimation is especially apparent in eight systems ("cbnu" and "umdhcil") that give all messages a score of "Critical". Within groups variations are also low, with many groups' systems returning the same average criticality score. Removing these eight systems yields an average criticality score of $\mu = 0.5053$, which is closer to the assessors' scores but still overestimating importance. We also note the lack of correlation between systems performing well on information type categorization and those performing well on information criticality estimation.

CONCLUSIONS

This paper describes the 2018 edition of the TREC-IS initiative. TREC-IS 2018 developed test collections and evaluation methodologies for automatic and semi-automatic filtering approaches that identify and categorize information and aid-requests made on social media during crisis situations. It also provides an evaluation challenge in which researchers/developers can participate. This paper also provides an overview of TREC-IS's evaluation methodology, an ontology of emergency information types, and summarizes the creation of a large dataset of 19,784

[8]Although we note the macro averaging across information types being performed here may be masking higher error rates on the rarer information criticality levels (Critical and High).

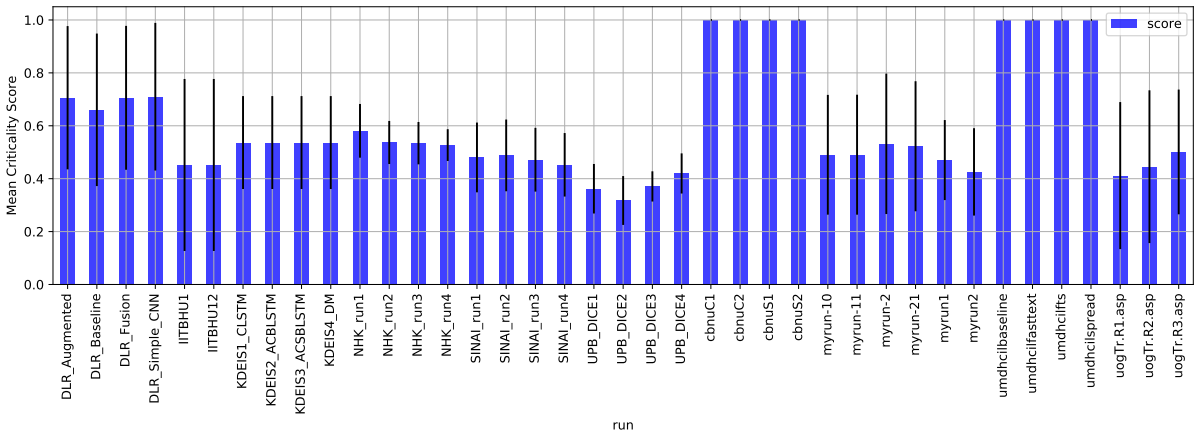


Figure 4. Mean Critical Scores Per Run (+/- one standard deviation)

hand-labeled social media messages from Twitter, in which assessors identified actionable and critical information for each event.

In addition, we examine this labelled Twitter data, showing the amount of actionable information for emergency response officers on Twitter is significant (up-to 10% post-filtering), but varies greatly with event type. This result is supported by information criticality labels produced by our assessors, which indicates that ~15% of tweets were judged as being of 'High' or 'Critical' importance to response officers.

Finally, as an evaluation challenge, eleven teams participated in TREC-IS 2018. This paper summarizes performances of these systems and implications for the maturity of the state-of-the-art. Given the eleven participating teams and 39 submitted systems, we show the current state-of-the-art is not sufficiently effective to be considered deployable by end users. While participants are relatively effective at identifying common information types such as news reports and sentiment, identifying actionable information types like search and rescue requests is still challenging. Alternatively, systems are more accurate at estimating information criticality, although they tend to over-estimate.

TREC-IS has been approved to run at TREC 2019, yielding an opportunity to develop larger, more robust, and standardized assessment datasets spanning multiple years, thereby reducing this reliance on training data and allowing technologists to better serve responders' needs. Up-to-date information and all of the data for the track are available from the TREC-IS track website:

http://trecis.org

ACKNOWLEDGMENTS

This work was supported by the Incident Streams Project sponsored by the Public Safety Communication Research Division at the National Institute of Standards and Technology (NIST, US).

REFERENCES

Abel, F., Hauff, C., Houben, G.-J., Stronkman, R., and Tao, K. (2012). "Twitcident: fighting fire with information from social web streams". In: *Proceedings of WWW*. ACM.

Barrenechea, M., Anderson, K. M., Aydin, A. A., Hakeem, M., and Jambi, S. (2015). "Getting the query right: User interface design of analysis platforms for crisis research". In: *Proceedings of ICWE*. Springer.

Castillo, C. (2016). *Big crisis data: social media in disasters and time-critical situations*. Cambridge University Press.

Castillo, C., Mendoza, M., and Poblete, B. (2013). "Predicting information credibility in time-sensitive social media". In: *Internet Research* 23.5.

Chowdhury, S. R., Imran, M., Asghar, M. R., Amer-Yahia, S., and Castillo, C. (2013). "Tweet4act: Using incident-specific profiles for classifying crisis-related messages." In: *Proceedings of ISCRAM*. Citeseer.

De Longueville, B., Smith, R. S., and Luraschi, G. (2009). "Omg, from here, i can see the flames!: a use case of mining location based social networks to acquire spatio-temporal data on forest fires". In: *Proceedings of SIGSPATIAL*. ACM.

Diakopoulos, N., De Choudhury, M., and Naaman, M. (2012). "Finding and assessing social media information sources in the context of journalism". In: *Proceedings of SIGCHI*. New York, NY, USA: ACM.

FEMA (2011). *FEMA National Incident Support Manual*. Tech. rep. Federal Emergency Management Agency, US.

FEMA (2013). *IS-42: Social Media in Emergency Management*. https://training.fema.gov/is/courseoverview.aspx?code=IS-42.

Ghosh, S., Ghosh, K., Ganguly, D., Chakraborty, T., Jones, G. J., and Moens, M.-F. (2017). "ECIR 2017 Workshop on Exploitation of Social Media for Emergency Relief and Preparedness (SMERP 2017)". In: *SIGIR Forum* 51.1.

Hiltz, S. R., Kushma, J. A., and Plotnick, L. (2014). "Use of Social Media by US Public Sector Emergency Managers: Barriers and Wish Lists." In: *Proceedings of ISCRAM*.

Hughes, A. L. and Palen, L. (2009). "Twitter adoption and use in mass convergence and emergency events". In: *International journal of emergency management* 6.3-4.

Imran, M., Castillo, C., Lucas, J., Meier, P., and Vieweg, S. (2014). "AIDR: Artificial intelligence for disaster response". In: *Proceedings of WWW*. ACM.

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., and Meier, P. (2013). "Extracting information nuggets from disaster-related messages in social media." In: *Proceedings of ISCRAM*.

Imran, M., Mitra, P., and Castillo, C. (2016). "Twitter as a lifeline: Human-annotated twitter corpora for NLP of crisis-related messages". In: *Proceedings of LREC*.

Kumar, S., Morstatter, F., Zafarani, R., and Liu, H. (2013). "Whom should i follow?: identifying relevant users during crises". In: *Proceedings of Hypertext*. ACM.

Lin, J., Efron, M., Wang, Y., and Sherman, G. (2014). *Overview of the trec-2014 microblog track*. Tech. rep. MARYLAND UNIV COLLEGE PARK.

Lin, J., Roegiest, A., Tan, L., McCreadie, R., Voorhees, E., and Diaz, F. (2016). "Overview of the TREC 2016 real-time summarization track". In: *Proceedings of the 25th text retrieval conference, TREC*. Vol. 16.

McCreadie, R., Santos, R. L. T., Macdonald, C., and Ounis, I. (2018). "Explicit Diversification of Event Aspects for Temporal Summarization". In: *ACM Trans. Inf. Syst.* 36.3.

Middleton, S. E., Middleton, L., and Modafferi, S. (2014). "Real-time crisis mapping of natural disasters using social media". In: *IEEE Intelligent Systems* 29.2.

Mileti, D. (1999). *Disasters by design: A reassessment of natural hazards in the United States*. Joseph Henry Press.

O'Dell, J. (2011). *How We Use Social Media During Emergencies*. https://mashable.com/2011/02/11/social-media-in-emergencies.

Olteanu, A., Castillo, C., Diaz, F., and Vieweg, S. (2014). "CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises." In: *Proceedings of ISCRAM*.

Olteanu, A., Vieweg, S., and Castillo, C. (2015). "What to expect when the unexpected happens: Social media communications across crises". In: *Proceedings of CSCW*. ACM.

Palen, L. and Liu, S. B. (2007). "Citizen communications in crisis: anticipating a future of ICT-supported public participation". In: *Proceedings of SIGCHI*. ACM.

Plotnick, L., Hiltz, S. R., Kushma, J. A., and Tapia, A. H. (2015). "Red Tape: Attitudes and Issues Related to Use of Social Media by US County-Level Emergency Managers." In: *Proceedings of ISCRAM*.

Reuter, C., Backfried, G., Kaufhold, M., and Spahr, F. (2018). "ISCRAM turns 15: A Trend Analysis of Social Media Papers 2004-2017". In: *Proceedings of ISCRAM*.

Reuter, C., Heger, O., and Pipek, V. (2013). "Combining real and virtual volunteers through social media." In: *Proceedings of ISCRAM*.

Reuter, C., Marx, A., and Pipek, V. (2012). "Crisis management 2.0: Towards a systematization of social software use in crisis situations". In: *International Journal of Information Systems for Crisis Response and Management* 4.1.

Robertson, S. E., Walker, S., Jones, S., Hancock-Beaulieu, M. M., Gatford, M., et al. (1995). "Okapi at TREC-3". In: *Nist Special Publication Sp* 109.

Rogstadius, J., Vukovic, M., Teixeira, C., Kostakos, V., Karapanos, E., and Laredo, J. A. (2013). "CrisisTracker: Crowdsourced social media curation for disaster awareness". In: *IBM Journal of Research and Development* 57.5.

Saleem, H. M., Xu, Y., and Ruths, D. (2014). "Novel Situational Information in Mass Emergencies: What does Twitter Provide?" In: *Procedia Engineering* 78.

Shaw, F., Burgess, J., Crawford, K., Bruns, A., et al. (2013). "Sharing news, making sense, saying thanks: Patterns of talk on Twitter during the Queensland floods". In: *Australian Journal of Communication* 40.1.

Tapia, A. H., Moore, K. A., and Johnson, N. J. (2013). "Beyond the trustworthy tweet: A deeper understanding of microblogged data use by disaster response and humanitarian relief organizations." In: *Proceedings of ISCRAM*.

Truelove, M., Vasardani, M., and Winter, S. (2015). "Towards credibility of micro-blogs: characterising witness accounts". In: *GeoJournal* 80.3.

Whipkey, K. and Verity, A. (2015). "Guidance for incorporating big data into humanitarian operations". In: *New York: UN-OCHA and the Digital Humanitarian Network's community of interest on Decision Makers Needs. http://digitalhumanitarians. com/sites/default/files/resource-field_media/IncorporatingBigDataintoHumanitarianOps-2015. pdf. Accessed May* 2, p. 2017.

Zade, H., Shah, K., Rangarajan, V., Kshirsagar, P., Imran, M., and Starbird, K. (2018). "From Situational Awareness to Actionability: Towards Improving the Utility of Social Media Data for Crisis Response". In: *Proceedings of the ACM on Human-Computer Interaction* 2.CSCW.

Detecting Disaster Recovery Activities via Social Media Communication Topics

Yuya Shibuya
The University of Tokyo
The Graduate School of Interdisciplinary Information Studies
shibuysyuya@gmail.com

Hideyuki Tanaka
The University of Tokyo
The Graduate School of Interdisciplinary Information Studies
tanaka@iii.u-tokyo.ac.jp

ABSTRACT

Enhancing situational awareness by mining social media has been widely studied, but little work has been done focusing on recovery phases. To provide evidence to support the possibility of harnessing social media as a sensor of recovery activities, we examine the correlations between topic frequencies on Twitter and people's socio-economic recovery activities as reflected in the excess demand for used cars and housing, after the Great East Japan Earthquake and Tsunami of 2011. Our research suggests that people in the disaster-stricken area communicated more about recovery and disaster damages when they needed to purchase used cars, while the non-local population communicated more about going to and supporting the disaster-stricken area. On the other hand, regarding the excess demand for housing, when the local population of the disaster-stricken area started to resettle, they communicated their opinions more than in other periods about disaster-related situations.

Keywords

Social Media, Topic modeling, Socio-economic recovery, Used-car demand, Housing demand.

INTRODUCTION

There have been various efforts to use social media data to detect the situation surrounding disaster-stricken communities. However, few studies focus on detecting recovery. This paper explores the possibilities of detecting socio-economic recovery activities by exploring social media communication topics and market data. To build resilient communities after a large-scale disaster, improving mid-to-long-term situational awareness could enhance recovery efforts. This is because traditional socio-economic recovery indicators (e.g., observing changes in population and consumption, and conducting questionnaire surveys) are not published in a real-time way. Social media data hold the possibility of filling this gap by its timeliness. This study conducts topic analysis on Twitter communication data for the first six months after the Great East Japan Earthquake and Tsunami of 2011, and looks into the relationships between the topic appearance ratios and two types of socio-economic activities, namely, excess demand for used cars and excess demand for housing. The Great East Japan Earthquake and Tsunami occurred on March 11th, 2011. It caused devastating building damage across the coastal areas. According to the Japanese Fire and Disaster Management Agency[1], 19,667 people were killed, and 2,566 people went missing. The disaster destroyed 121,787 buildings.

This study takes these two goods as proxies of people's socio-economic recovery activities to rebuild their daily-lives because related research and reports have demonstrated that both used cars and housing are in higher demand in affected communities when a large-scale water-related disaster hits (the details are explained later). According to Drabek (1986), a disaster involves four phases: (1) preparedness, (2) response, (3) recovery, and (4) mitigation. This study focuses on the recovery phase. We particularly analyze the data collected during the first six months after the disaster.

The rest of the paper is constructed as follows. First, we review related literature and introduce research questions. Secondly, the data are described. Then we conduct topic analysis on social media communication data and topic frequency scores are calculated. To analyze the possibility of using social media data as a sensor of recovery activities, we analyze the correlations between the topic frequency ratios and the proxies of socio-economic

[1] http://www.fdma.go.jp/bn/higaihou_new.html

recovery activities. Lastly, we explain and discuss the results, and conclude with implications for future study.

RELATED LITERATURE

Socio-economic Recovery Activities: The Excess Demand for Used Cars and Housing

When a large-scale water-related disaster (e.g., hurricane, typhoon, tsunami) hits a community, there tends to be an excess demand for used cars and for housing in the local community. For example, after Hurricane Harvey and Irma in 2017, the media reported excess demand for used cars around the flooded areas (Breuninger, 2017; Chee, 2017; Lang, 2017). Likewise, after the Great East Japan Earthquake and Tsunami, newspapers reported a rise in the demand for used cars in the disaster-stricken area to replace water-damaged vehicles. Used cars were preferred over new cars because of their lower prices and quicker registration process (e.g., Nikkei Sangyo Shinbun, 2011, The Tohoku Finance Bureaus, 2017). In addition, Shibuya and Tanaka (2018a) conducted interviews with used-car dealers in disaster-stricken areas and revealed that the affected population needed to buy used cars when they became active in restarting their daily-lives (e.g., restarting working).

Regarding housing, various reports described the excess demand for non-inundated housing after a large-scale disaster. For instance, after Hurricane Sandy which flooded more than 300,000 homes and approximately 23,400 businesses (Bloomberg, 2013, p.13), the media reported increased demand for dry houses near the damaged areas (Kearns, Park and Buhayar, 2012; NBC, 2014; Racioppi, 2014). Another example of increased demand for housing occurred after the Great East Japan Earthquake and Tsunami, which destroyed 121,783 buildings across the coastal areas[2]. The newspapers reported that although the land values declined in the inundation zones, lands located on hills were in higher demand, causing increased land prices (Asahi Shimbun, 2011).

Both used-car and housing market data have been widely analyzed based on the Hedonic model (e.g., Barr et al., 2017; Haan and Boer, 2010; Hallstrom and Smith, 2005; Kooreman and Haan, 2006; McCoy and Zhao, 2018; McKen-zie and Levendis, 2010). The Hedonic model is an economic model that postulates that the price of a product reflects a bundle of embodied characteristics valued by some implicit or shadow prices (Prieto et al., 2015). With the Hedonic model, we can examine used-car/housing prices, which reflect the demand controlled by used-car/housing characteristics. For example, if there is excess demand for housing in a particular area, the prices of housing in the area may rise to re-equilibrate the excess demand. Also, if the amount of supply of goods is the same or more than those of corresponding periods of the previous year, the rises in prices could be explained by the excess demand. Therefore, although analyses focus on prices, the changes in prices controlled by the used-cars/housing characteristics also reflects excess demand for used cars/housing. The previous studies examined the used-car/housing market data by applying the Hedonic model and clarified the excess demand for used cars/housing after large-scale disasters. More specifically, Shibuya and Tanaka (2019) statistically showed that there was an excess demand for used cars, particularly for Light Motor Vehicles[3] in the disaster-stricken area after the Great East Japan Earthquake and Tsunami. Also, Shibuya and Tanaka (2018b) analyzed housing market data of New York City and found there was an excess demand for dry housing in New York City after Hurricane Sandy. Another empirical study (Shibuya and Tanaka, 2018c) analyzed the leased housing market data after the Great East Japan Earthquake and Tsunami, and found there was an excess demand for dry houses located within 3km to the building damage zones. These excess demands for both used cars and housing after the large-scale disasters can be used as proxies of one of the socio-economic disaster recovery activities because people in the disaster area needed these goods and were willing to pay to purchase them. Furthermore, as to used cars, the interviews with used-car dealers showed that people purchased used cars when they started to be active in rebuilding their daily lives, resuming their work and shopping (Shibuya and Tanaka, 2018a). Regarding housing, people from the disaster areas seeking new housing means that people moved their physical locations, for example, from an evacuation shelter to an apartment, and thus, were active in restarting their lives or moving forward to the next stage of recovery. Therefore, in this study, we use used-car and housing market data as proxies of socio-economic recovery activities in the case of the Great East Japan Earthquake and Tsunami.

Social Media for Improving Disaster Situational Awareness

When a disaster hits a community, a massive amount of information that includes individual discussions, and personal experiences and thoughts, is created. Because acquiring useful information about the situations in the disaster-stricken area is critical for relief operations and preventing further losses, social media users have been recognized as "people as sensors" (Laituri and Kodrich, 2008), "citizen sensing" (Castillo, 2016; Sheth, 2009), or " human sensors" (Yuan et al., 2013). Various related works have looked into the potential usefulness of social media as "people as sensors" by investigating the correlations between cyber and real-world activities. For instance, the relationships between chatter on Twitter and donation amounts (Korolov et al., 2015), the proximity

[2] http://www.fdma.go.jp/bn/higaihou_new.html (accessed September 30, 2018, in Japanese)
[3] A Japanese car category whose engine volumes are 660cc or less.

of a hurricane path and social media activities (Kryvasheyeu et al., 2016), and sentiment on social media and actual disaster damage (Guan and Chen, 2014; Kelly and Ahmad, 2014; Nguyen et al., 2014) have been addressed. Also, other researchers argue that social media can be used as earthquake detectors (Kropivnitskaya et al., 2017; Sakaki et al., 2013, 2010), water level sensors (de Albuquerque et al., 2015; Zhang et al., 2016), and sensors of evacuation activities (Kibanov et al., 2017; Martin et al., 2017; Wang et al., 2016; Yuan et al., 2013). These studies suggest that social media data can promote "people as sensor" approaches for disaster management by providing effective and near real-time complement data for detecting or assessing disaster-related incidents (Martin et al., 2017). However, little work has been done on adapting the "people as sensors" approach in recovery. Some of the examples of studies focusing on social media use in recovery are Su et al (2017) and Yan et al. (2017). Yan et al. (2017) analyzed geotagged Flickr (a photo-based social network) photos after the 2013 Earthquake and Typhoon in the Philippines (ranging from April 2004 to July 2016) to identify remaining damage by mining tourist photos. Su et al. (2017) investigated the social media communication patterns after the Great East Japan Earthquake and Tsunami by focusing mainly on nueclear-related topics. In terms of the recovery phase, social media data have the potential to complement traditional socio-economic recovery indicators (e.g., changes in population and consumption, and conducting questionnaire surveys) because such data can provide fine-grained measurements of behavior over time while taking advantage of significant population sample sizes (Gruebner et al., 2017). Detecting recovery activities in a near real-time way may help recovery-related agencies, local public officials and recovery practitioners to obtain a big picture. Furthermore, improving the affected areas' real-time situational awareness may help create an evidence-based and more effective recovery plan.

Local and Non-local to a Disaster

In terms of social media communication data after a large-scale disaster, existing studies have recognized different communication patterns between locals and non-locals during disasters. Starbird et al. (2012) argue that social media contents shared by local citizens in a disaster-stricken area can provide unique and critical information for emergency responders and other diverse stakeholders. Kogan et al. (2015) and Starbird and Palen (2010) found that Twitter users, in general, were more likely to re-tweet the accounts of people local to emergency events. Bica et al. (2017) investigated an imaginary representation of a disaster via images shared on Twitter. They found that locals focus more on the business details of the response and the damage in their cities while a non-local population focus more on the images of people suffering (Bica et al., 2017). In addition, there have been various efforts to make it easier to find communication posted by people local to disaster-stricken areas. For example, Grace et al. (2017) investigate how to effectively discover local populations by using social network ties. Other typical ways to identify local communications are using disaster-related keywords and location-based tweet collections (Olteanu et al., 2014). This study also applies the keyword-based tweet collection and divides local and non-local communication according to whether communication contains disaster-impacted locations' names (details are described in the Data section).

RESEARCH QUESTIONS

Based on the previous studies cited above, this study investigates the following three research questions. First, although only limited research has been done on whether or not we can improve situational awareness during recovery phases and how we can do so, using social media data as a sensor of recovery activities has the potential to improve recovery efforts because social-media generated information may be able to complement existing recovery indicators by its timeliness. Thus, for the first step to explore the possibility of using social media data to detect recovery activities, we analyze whether there were correlations between people's communication in the virtual world and people's activities in the real world.

- RQ1: Did social media communication topics have relationships with the excess demand for used cars and housing in the disaster-stricken area?

Secondly, although both used cars and housing are likely to be in higher demand after a large-scale water-related disaster, the two goods have different characteristics and thus, when and which people in the disaster-stricken area needed to buy these two goods may be different. In this study, our hypothesis is that the two types of goods had different types of correlations with social media communication.

- RQ2: Did the excess demand for used cars and the excess demand for housing correlate differently with social media communication?

Lastly, related works investigating relatively short-term restoration and response found the different types of communication patterns between people local to a disaster-stricken area and people non-local to the disaster. Our hypothesis in this study is that even during recovery phases, the local and non-local population communicate differently, and thus we consider the following RQ3.

- RQ3: Did social media communication posted by people local and non-local to the disaster-stricken area have different types of correlations with the excess demand for used cars and housing?

DATA

Socio-economic Recovery Activity Data

Used-car market data

As one of the proxies of socio-economic recovery activities, we use the Japanese used-car market data sourced from advertisements posted on one of the most dominant used-car magazines in Japan, "Goo[4]," which is published every two weeks. We used the data posted by dealers in the tsunami-damaged areas for six months after the disaster. For the analysis, we selected a body type named Light Motor Vehicle Cab Van because both quantitative research (Shibuya and Tanaka, 2019) and qualitative reports, such as interviews in the newspaper and in government reports showed that there was an excess demand for the Light Motor Vehicle Cab Van. The data include used-car characteristics such as age, price, and transmission. The real prices of used cars were calculated based on the fiscal 2015 Consumer Price Index[5].

Housing market data

This study uses the leased housing market data from six months after the disaster provided by At Home Co., Ltd[6]. The data include housing characteristics such as the lease price, the size of the building area, the age of a property, and the address. The lease prices were adjusted as real prices with the residential property price index[7]. To exclude outliers, the real sales price per square meters of each property was calculated. Properties whose price per square meter was more than or less than the mean real sales price ± the standard deviation × 4 were excluded. Each property was checked to see if it was in the building damaged zones, and if not, the distance to the building damage zones was calculated based on the survey results of building damages conducted by the Ministry of Land, Infrastructure, Transport, and Tourism[8]. The distance from each property to Sendai station as a proxy of the city center was calculated. The minutes from the nearest station of each property to Sendai station by a train was also added as a feature. The current study only uses the leased houses located in plains and within 3km to the building damage zones because the quantitative research (Shibuya and Tanaka, 2018c) reveals that there was an excess demand for leased properties, particularly those located in plains and within 3km to the building damage zones. Table 1 describes the numbers of used cars and housing for the analysis every two weeks.

Table 1. Observation numbers of used cars and housing every two weeks

	Mar-2	***Apr-1***	***Apr-2***	***May-1***	***May-2***	***Jun-1***	***Jun-2***	***Jly-1***	***Jly-2***	***Aug-1***	***Aug-2***	***Sep-1***
Used Cars	14	118	132	124	129	114	114	104	104	134	106	121
Housing	656	287	436	343	468	389	344	363	349	309	348	266

Note 1: Mar-1 represents the first half of March; Mar-2 represents the second half of March. The same applies hereafter.
Note 2: In this study, we set a one-month time lag for used-car data because our used-car target data are sourced from a paper-based magazine. It took about one month for the magazine to be organized and to publish the data after collecting data from town shops. For example, in this study, used-car data from the second half of April (*Apr-2*) is treated as the second half of March (*Mar-2*). On the other hand, we did not set any time lags for housing market data because they are sourced from an online platform, and they were published in real-time way.

Social Media Communication Data: Twitter Data

Twitter is a platform that allows users to post messages (tweets) to their followers and the public (if a user permits), and to receive posted messages from other users. The target data in this study were collected through an Internet service called "Kuchikomi@kakaricho" (http://kakaricho.jp)[9]. We selected Japanese tweets posted for six months after the disaster (March 11th to September 11th of 2011) that contained at least one of the 16 Japanese keywords deemed to be relevant to our study purposes:[10] "earthquake," "disaster," "affected," "evacuation," "thank you," "temporal," "restart," "recovery," "information," "appreciation," "support," "tsunami," "damaged," "car," "light,"

[4] The used-car data were provided by "Proto corporation" which publish "Goo."
[5] We used "automobile" deflator sourced from http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001074278&cycode=0 (accessed October 17, 2018).
[6] The study is supported by Joint Research Program No.823 at CSIC, The University of Tokyo ("Real Estate Database 1999-2016" by At Home Co., Ltd.)
[7] Average of 2010 = 100, http://www.mlit.go.jp/totikensangyo/totikensangyo_tk5_000085.html, accessed September 21st, 2018
[8] http://www.mlit.go.jp/toshi/toshi-hukkou-arkaibu.html
[9] Although Twitter API allows collecting public tweets, we cannot collect tweets seven years ago (when the disaster happened). Therefore, we use an internet service Kuchikomi@kakaricho which provides historical tweets.
[10] We applied keywords-based tweets search approach based on related works (e.g., Wendland et al, 2017; Musaey et al., 2017; Alam et al., 2017). Before selecting the 16 keywords, the authors manually checked various types of tweets relevant to the disaster. After discussing the appropriateness of the keywords among authors, we carefully chose 16 Japanese keywords.

"evacuation" (all keywords are translated by the authors). In total, we collected 11,676,929 tweets.

Selection of disaster-related communication based on machine-learning

To select social media communication that related to the disaster, we classify the originally collected data based on machine learning techniques. First, after removing duplicated and re-tweeted tweets from the initially collected data, we randomly sampled a subset of about 2,000 tweets. After manually annotating the subset of 2,000 tweets based on whether the subset was disaster-related or not, we developed several classifiers including Naive Bayes, Support Vector Machine (SVM), and Logistic Regression along with a 10-fold cross-validation technique to compare the accuracy of these classification models. We found that the Naive Bayes classifier is the best predictor (Accuracy: 0.932, Precision: 0.945, Recall: 0.939)[11]. We then predicted and labeled the rest of the Twitter data with the Naive Bayes classifier. As a result, this study labeled 817,084 tweets as disaster-related. For further research, we only use these disaster-related labeled tweets.

Table 2. The Number of Local and Non-Local Tweets Datasets

	Number of Tweets											
	Mar-2	***Apr-1***	***Apr-2***	***May-1***	***May-2***	***Jun-1***	***Jun-2***	***July-1***	***July-2***	***Aug-1***	***Aug-2***	***Sep-1***
Local	728	549	393	529	401	357	415	385	322	326	307	463
Non-Local	209,346	94,748	60,211	48,653	47,174	49,436	43,040	50,053	42,699	41,301	45,270	79,978

Selection of tweets posted from the local and non-local population

As a means to examine whether a communication posted by the local and non-local population had different types of relationships with the excess demand for used cars and houses (RQ3), we further categorized the data based on tweets with geo-information. We made two datasets; a *Local Tweets dataset* and a *Non-Local Tweets dataset*. The *Local Tweets dataset* consists of tweets either whose tweeters' profile shows that they were in tsunami-stricken cities[12], their profile description contains any of the tsunami-stricken cities' names, or tweets with geo-tagged information that declares that they were in the tsunami-stricken area. The *Non-Local Tweets dataset* are the remainder of the data. Table 2 shows the number of each dataset every two weeks.

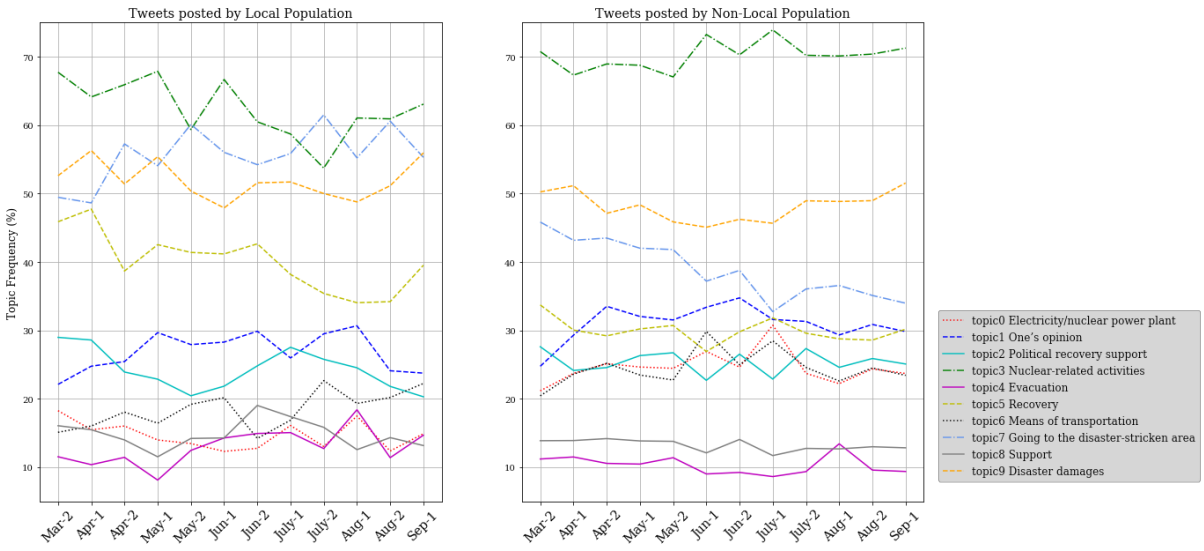


Figure 1. Topic Frequency ratio (T_i^n) of Tweets Posted by Local and Non-Local Populations

[11] SVM: Accuracy: 0.592, Precision: 0.592, Recall: 0.992. Logistic Regression: Accuracy: 0.928, Precision: 0.933, Recall: 0.9458.
[12] This study uses tsunami-stricken cities' names listed on the "Area of inundated area" by the Geospatial Information Authority of Japan (http://www.gsi.go.jp/kikaku/kikaku60004.html). We only used tsunami-stricken cities' names in Miyagi prefecture and Iwate prefecture. Fukushima prefecture was also one of the devastated areas of the disaster, but we did not include cities in Fukushima prefecture because Fukushima prefecture suffered more from the nuclear incident and thus, it should be treated differently.

Table 3. LDA topics

#	Proposed label	Top 10 most probable words	Tweet examples
0	Electricity/nuclear power plant	restart, power saving, summer, rice, electricity, non-nuclear power, shortage, Kesennuma (city name), Hokkaido (region name), machine	"Now is not the time to criticize the government, but the time to look at the reality and figure out what we have to do. Radioactive substances are detected but we need electricity, and we cannot store it up."
1	One's opinion	think, oneself, thing, myself, say, appreciation, watch, what, now, direction	"I think it is unfair that you need a local government's permission to send relief supplies. I cannot believe that. We have watched affected towns suffering, and I think they have no time to give permission to individuals. "
2	Political recovery support	free, support, person, service, site, governor, consultation, minster, freely, photo	"The Councilors' budget committee will restart the day after tomorrow. I heard that members are preparing to consult about the disaster-stricken area's situations and how to support them."
3	Nuclear-related activities	recovery, nuclear power, Japan, evacuation, country, Fukushima, issue, say, government, China	"I met an elderly person who evacuated from the nuclear-affected area. The lifeline utilities are in need of repair, and we still have family there."
4	Evacuation	evacuation, children, child, shelter, kid, target, need, parent, work, school	"Several people asked us to evacuate to another country.", "Evacuation places are in need of diapers, water, and rice."
5	Recovery	affected-area, affected, recovery, land, use, message, think, smile, Japan, support	"To support recovery efforts, the company bought a boatload of fish."
6	Means of transportation	use, car, vehicle, tax increase, restoration, accident, technology, automobile, ization/ize, need	"We need to send gasoline for cars to the disaster-stricken area." "Timely recognition of priority issues is needed to send relief supplies to the disaster-stricken area." "The train line in the disaster-stricken area is moving towards recovery."
7	Going to the disaster-stricken area	car, go, think, come, inside, time, house, evacuation, go out, myself	"I went back to the disaster-affected area and saw many volunteers who came and helped with the cleaning." "Does anyone know the website informing people how to go or send supplies to the disaster-stricken area?"
8	Support	support, affected area, the Great East Japan Earthquake and Tsunami, recovery, direction, activity, volunteer, participation, recovery support	"If anybody is looking for a place to sleep, please come to Nihonmatsu town. There is a shelter." "We need to support one another." "Photographers are holding an exhibition to support the disaster-affected area."
9	Disaster damages	tsunami, earthquake damage, evacuation, information, occurrence, news, the Great East Japan Earthquake and Tsunami, Mainichi newspaper, Miyagi prefecture	"The height of the first tsunami was over 10 meters. The second one was over five meters." "Teachers and children of the school are still left behind on the third floor of the building in Miyagi prefecture."

Note: All original tweets are in Japanese. All tweets in the table are trasnlated by the authors.

Topic Analysis: Latent Dirichlet Allocation (LDA)

Before conducting the primary analysis, we conducted topic analysis to explore what kinds of topics were on Twitter after the disaster. In doing so, we applied the Latent Dirichlet Allocation (LDA). LDA is a probabilistic topic modeling widely used in natural language processing to summarize and extract topics from documents. The intuition behind LDA is that documents exhibit multiple topics and a topic should be a distribution over a fixed vocabulary (Blei, 2012). When we manually looked into various tweets from the target dataset, we found each tweet could be categorized into several topics (for example, a tweet contains two topics; the disaster's damage and emotional encouragement). Thus, LDA, which assumes that one document contains multiple topics, was chosen for this analysis. By treating one tweet as one document, we conducted LDA with ten topics for the

predetermined topic number[13]. The ten topics found by LDA and the most probable terms and proposed labels are shown in Table 3. Next, every tweet in our dataset was automatically labeled with the ten topics based on the results of LDA; If a tweet had more than 10% probability of being categorized as topic *n*, the tweet was labeled as the topic of *n* related. Next, the topic frequency ratio (T_t^n) for every two weeks was calculated as follows: $T_t^n = \frac{Topic\ labeled\ Tweet_t^n}{All\ Tweet_t}$ where $All\ Tweet_t$ denotes the number of all tweets in *t* period and $Topic\ labeled\ Tweet_t^n$ denotes the number of tweets labeled with the topic of *n* in *t* period. Figure 1 describes the chronological changes of the topic frequency ratio (T_t^n) of tweets posted by local and non-local populations, respectively.

Table 4. The statistical summary of equation (1) for each body type (six months pooled data)

	Used Cars (n=1,314)					Housing (n = 4,558)			
	mean	std	min	max		mean	std	min	max
lnP	13.07	0.53	11.00	14.20	*lnP*	10.63	0.31	8.82	11.88
X_1	0.29	0.45	0.00	1.00	X_1	0.68	0.47	0.00	1.00
X_2	0.00	0.06	0.00	1.00	X_2	0.01	0.00	0.00	0.03
X_3	7.37	4.25	0.00	21.00	X_3	0.02	0.04	0.00	0.17
X_4	0.31	0.46	0.00	1.00	X_4	0.02	0.01	0.00	0.12
L0	0.14	0.02	0.12	0.18	X_5	0.02	0.01	0.00	0.07
L1	0.27	0.02	0.22	0.31	X_6	0.03	0.01	0.01	0.17
L2	0.24	0.03	0.2	0.29	X_7	0.00	0.00	0.00	0.02
L3	0.62	0.04	0.54	0.68	*L0*	0.15	0.02	0.12	0.17
L4	0.13	0.03	0.08	0.18	*L1*	0.27	0.02	0.24	0.31
L5	0.4	0.04	0.34	0.48	*L2*	0.24	0.03	0.2	0.29
L6	0.18	0.02	0.14	0.23	*L3*	0.64	0.03	0.59	0.68
L7	0.56	0.04	0.49	0.61	*L4*	0.13	0.03	0.08	0.18
L8	0.15	0.02	0.12	0.19	*L5*	0.4	0.04	0.34	0.48
L9	0.52	0.02	0.48	0.56	*L6*	0.18	0.02	0.16	0.22
NL0	0.25	0.02	0.21	0.31	*L7*	0.54	0.02	0.49	0.56
NL1	0.32	0.02	0.25	0.35	*L8*	0.14	0.02	0.12	0.17
NL2	0.25	0.02	0.23	0.28	*L9*	0.52	0.03	0.48	0.56
NL3	0.7	0.02	0.67	0.74	*NL0*	0.26	0.03	0.22	0.31
NL4	0.1	0.01	0.09	0.13	*NL1*	0.31	0.02	0.29	0.33
NL5	0.3	0.01	0.27	0.34	*NL2*	0.24	0.01	0.23	0.26
NL6	0.25	0.02	0.2	0.3	*NL3*	0.71	0.02	0.67	0.74
NL7	0.39	0.04	0.33	0.46	*NL4*	0.1	0.02	0.09	0.13
NL8	0.13	0.01	0.12	0.14	*NL5*	0.3	0.02	0.27	0.32
NL9	0.48	0.02	0.45	0.51	*NL6*	0.26	0.03	0.23	0.3
					NL7	0.38	0.04	0.33	0.43
					NL8	0.13	0.01	0.12	0.14
					NL9	0.48	0.02	0.45	0.52

Note 1: L_k denotes the topic frequency ratio of topic *k* within the *Local Tweets dataset.* NL_k in the table denotes the topic frequency ratio of the topic *k* within the *Non-Local Tweets dataset.*

MODEL

To address how the topic frequency ratio on Twitter correlated with used-car prices, we developed a model below (equation 1) based on the Hedonic model as described in the section on Related Literature. By controlling used-car/housing characteristics, such as age and how many kilometers were driven, the Hedonic model allows us to assess the correlation between the used-car/housing prices, which reflect the demand for used-car/housing, and the topic frequency ratios on Twitter.

$$\ln P_i = \beta_0 + \beta_j X_{ji} + \beta_k T_{ki} + \varepsilon_i \quad (1)$$

where $\ln P_i$ is the natural logarithm of the real price of the *i* th product, X_{ji} is a vector of *j* th observable characteristics of the used cars or the houses. T_{ki} is the *k* th topic frequency ratio (L0 to T9 and NL0 to NL9 in

[13] To decide a suitable number of topics, the author applied LDA with several topic numbers, including 10, 20, 30, 50 and 100. As a result, when the topic number is 10, the results are most convincing and understandable to people although the perplexity is not the best.

Table 4). ε_i is the error term. We apply equation 1 to each topic frequency ratio[14] and used-car and housing market data respectively. For the used-car market data, the following control variables X_i are used:
Transmission:
X_{1i} = Transmission Dummy (Automatic=1, others=0)
Fuel:
X_{2i} = Special types of fuels Dummy (LPG, CNG or FC=1, others = 0)
Age:
X_{3i} = Age (in years)
Kilometers driven:
X_{4i} = 100,000km Dummy (over 100k km driven=1, others=0)

For the housing market data, the following control variables X_i are used:
X_{1i} = Apartment dummy (apartment = 1, others = 0)
X_{2i} = Distance to Sendai station (1/1000 km)
X_{3i} = Time from the nearest station to Sendai station by a train/subway (1/1000 minutes)
X_{4i} = Age (1/1000 year)
X_{5i} = Accessibility to the nearest station by walking (1/1000 min)
X_{6i} = Size of building area (1/1000 m^2)
X_{7i} = Height of a property (the sum of property's levels × 1/1000)

The statistical summary of our model is shown in Table 4.

RESULT

Table 5 shows a summary of the estimated coefficients of the topic frequency ratios (T_{ki}) of equation 1[15]. In the table, if an estimated coefficient of a topic frequency ratio has a significant correlation with the excess demand of used cars or housing at a 5% significance level, the cell is shaded. Other estimated coefficients of our model and adjusted R^2 are presented in Tables 6 and 7.

Regarding the excess demand for used cars, there were significant positive correlations between the used-car demand and the topic frequency ratio of Topic 3 (Nuclear-related activities), Topic 5 (Recovery), and Topic 9 (Disaster damages) within the *Local Tweets dataset*. On the other hand, there were significant negative correlations between the used-car demand and the topic frequency ratio of Topic 4 (Evacuation) within the *Local Tweets dataset*. In contrast, there were significant positive correlations of the topic frequency ratio of Topic 7 (Going to the disaster-stricken area) and Topic 8 (Support) with the prices of used cars within the *Non-local Tweets dataset.*

Regarding excess demand for housing, there were statistically significant positive correlations between the excess demand for housing and the topic frequency ratio of Topic 1 (Electricity/nuclear power plant) and Topic 6 (Means of transportation/ logistics) within the *Local Tweets* dataset. On the other hand, we did not find any significant correlations between the demand for housing and the topic frequency ratios within the *Non-Local Tweets* dataset.

Table 5. Estimated Coefficients of Topic Frequency Ratio

		Topic0	Topic1	Topic2	Topic3	Topic4	Topic5	Topic6	Topic7	Topic8	Topic9
		Electricity/ nuclear power plant	One's opinion	Political recovery support	Nuclear-related activities	Evacuation	Recovery	Means of transportation	Going to the disaster-stricken area	Support	Disaster damages
Used cars	Local	0.19	-0.49	0.06	**0.56****	**-1.08*****	**0.64****	-0.62	-0.41	-0.48	**0.96****
	Non-Local	-0.37	-0.06	0.41	-1.05	0.42	0.74	-0.51	**0.94*****	**3.22****	0.48
Housing	Local	-0.14	**0.25*****	-0.11	**-0.16****	0.07	-0.07	**0.24****	0.13	-0.12	-0.05
	Non-Local	-0.08	0.08	0.23	-0.2	0.1	-0.07	-0.06	-0.04	-0.01	0.01

Note1: **: $p < 0.05$, ***: $p < 0.01$. The same applies hereafter.

[14] We apply equation (1) to each topic frequency ratio respectively because the correlations between each topic are from 0.08 to 0.8 and several topic frequency ratios would cause multicollinearity.
[15] We note that this study uses relatively large numbers of observations, and statistical significances (p-values) do not directly estimate the strength of related variables. Among the statistically significant topic frequency ratios (Tk), the largest effect size (Cohen's f^2) is 0.01. Future studies need to analyze how to improve accuracy of estimating disaster recovery activities with social media related variables by, for example, applying other social media related variables and by applying different models.

Note2: We found that both heteroskedasticity and serial correlation exist (Breusch-Pagan statistics' p-value are all less than 0.01. Durbin-Watson statistics' p-values are less than 0.01). Therefore, the standard errors are corrected for serial correlation and heteroscedasticity by using the Newey-West procedure.

Note3: The Variance Inflation Factor (VIF) of each regression for the housing datasets is from 1.00 to 2.08. The VIF of each regression for used cars is from 1.00 to 1.18. These VIF scores suggest there are no multicollinearity problems.

Table 6. The results of equation (1) within the *Local Tweets dataset*

	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	*Topic3*			
Used cars	0.70	Estimate	13.42***	0.04**	0.05	-0.08***	-0.35***	**0.56****			
		Std. Error	0.17	0.02	0.19	0.00	0.02	0.26			
	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	*Topic4*			
	0.70	Estimate	13.91***	0.04*	0.07	-0.08***	-0.36***	**-1.08*****			
		Std. Error	0.05	0.02	0.17	0.00	0.02	0.40			
	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	*Topic5*			
	0.70	Estimate	13.52***	0.04**	0.08	-0.08***	-0.35***	**0.64****			
		Std. Error	0.11	0.02	0.18	0.00	0.02	0.27			
	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	*Topic9*			
	0.70	Estimate	13.28***	0.04**	0.06	-0.08***	-0.35***	**0.96****			
		Std. Error	0.19	0.02	0.18	0.00	0.02	0.38			
Housing	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	X_5	X_6	X_7	*Topic1*
	0.71	Estimate	10.43***	-0.07***	-4.49***	-0.33***	-14.45***	-2.07***	14.89***	10.72***	**0.25*****
		Std. Error	0.03	0.01	0.72	0.09	0.61	0.23	0.45	1.99	0.09
	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	X_5	X_6	X_7	*Topic3*
	0.71	Estimate	10.60***	-0.07***	-4.47***	-0.34***	-14.47***	-2.07***	14.87***	10.83***	**-0.16****
		Std. Error	0.04	0.01	0.72	0.09	0.61	0.23	0.45	1.99	0.06
	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	X_5	X_6	X_7	*Topic6*
	0.71	Estimate	10.46***	-0.07***	-4.44***	-0.33***	-14.45***	-2.05***	14.86***	10.89***	**0.24****
		Std. Error	0.03	0.01	0.72	0.09	0.61	0.23	0.45	1.98	0.11

Table 7. The results of equation (1) within the *Non-Local Tweets dataset*

	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	*Topic7*
Used cars	0.70	Estimate	13.41***	0.03*	0.07	-0.08***	-0.35***	**0.94*****
		Std. Error	0.14	0.02	0.19	0.00	0.02	0.34
	$Adj.R^2$		*Intercept*	X_1	X_2	X_3	X_4	*Topic8*
	0.70	Estimate	13.35***	0.04*	0.05	-0.08***	-0.35***	**3.22****
		Std. Error	0.20	0.02	0.18	0.00	0.02	1.48

DISCUSSION

By applying the Hedonic model, this study observed whether there were correlations between social media communication topics and the excess demand for used cars and housing as proxies of socio-economic recovery activities in the disaster-stricken area (RQ1). Also, we analyzed whether the excess demand for used cars and housing correlated differently with communication topics (RQ2) and whether there were any differences in social media communication posted by people local and non-local to the disaster-stricken area (RQ3). We present our discussion according to these research questions.

Regarding RQ1, by applying equation 1, we found that several topic frequency ratios had statistically significant correlations with the excess demand for used cars and housing. These results imply that the topic appearance ratios on Twitter might be useful in detecting people's socio-economic recovery activities in the real world.

Regarding RQ2, the results suggest that the different types of the two goods correlated to different topic frequency ratios. To be specific, regarding used cars, we found that the excess demand for used cars correlated to the frequency ratios of topics related to nuclear-related activities (Topic 3), evacuation (Topic 4), recovery (Topics 5) and damage (Topic 9) within the Local Tweets dataset. Also, the frequency ratios of topics related to going to (Topic 7) and supporting (Topic 8) the disaster-stricken area within the *Non-Local Tweets dataset* correlated with the excess demand for used cars. On the other hand, regarding housing, we found that the excess demand for housing correlated to frequency ratios of topics related to people's opinion (Topic1), nuclear activities (Topic3) and means of transportation/logistics (Topic 6) within the *Local Tweets dataset*. It is interesting to focus on topics related to nuclear activities (Topic 3) because the excess demand for both goods, used cars and housing, correlated with the topics (Topic3), but they correlated in different ways: The excess demand for used cars had positive correlations with nuclear activities while the excess demand for housing had negative correlations with the topic. This implies that because nuclear-related issues caused anxiety among people in the disaster-stricken area, they started to rent new places to resettle when uncertainty about nuclear-related issues gradually diminished. On the other hand, locals might have started to purchase used cars even while there were concerns related to nuclear-

related issues.

Regarding RQ3, the analysis implies that communication posted by locals and non-locals correlated differently with the excess demand for used cars. This study found that there were negative correlations between the used cars and the frequency ratios of topics related to evacuation (Topic 4). This implies that when people in the disaster-stricken area were still in evacuation shelters, there was less need to obtain or replace vehicles. Moreover, we found positive correlations between the excess demand for used cars and the frequency ratios of topics related to nuclear-related activities (Topics 3), recovery (Table 5) and damage (Topic 9) within the *Local Tweets dataset,* and topics related to going to and supporting the disaster-stricken area (Topics 7&8) within the *Non-Local Tweets dataset*. This implies that the local population might have communicated more about nuclear-related activities (Topic 3), recovery (Topics 5) and damage (Topic 9) while people became active in recovery efforts and restarted their daily lives as observed in the excess demand for used cars. Meanwhile, people outside of the disaster-stricken area tended to communicate more about going to and supporting the affected area (Topics 7&8). These results are similar to the findings of the previous study that found local people tended to share images of response, recovery and damages while the non-local population tended to share images of people suffering (Bica et al., 2017). This is because local residents needed to face realities and be strong in order to return back to normal routines while people from the outside may have tried to support the disaster-stricken area because they knew of local people's continuous struggles to recover. Our results imply that, for recovery phases, it is also important to distinguish communications posted by locals and non-locals.

In addition, regarding housing demand, we found positive correlations between the excess demand for housing and the frequency ratios of topics related to people's opinions (Topic1) and the means of transportation/logistics (Topic 6) within the *Local Tweets dataset* while there were no correlations between topic frequency ratios within the *Non-Local Tweets dataset* and the excess demand for housing. These results imply that people in the disaster-stricken area started to express their opinions about the situations surrounding them, such as recovery progress while people in the disaster-stricken area started to resettle as observed in the excess demand for housing. Although it is difficult to interpret the correlations between the excess demand for housing and the topic frequency ratios of topics related to transportation means (Topic6), this result might be reflected in the contents of tweets labeled as Topic 6. The tweets categorized as Topic 6 include less communication about car scarcity and the need to buy cars while Topic 6 tweets include more communication about a lack of gas, which might have tended to occur after people purchased used cars, and more communication about public transportation system recovery updates (e.g., tweets sharing the information about train service status).

CONCLUSION

The object of this study was to address how social media data could be used for detecting recovery in disaster-stricken communities. We empirically analyzed the correlations between topic frequency variations in disaster-related tweets after the Great East Japan Earthquake and Tsunami of 2011 and two types of proxies of socio-economic recovery activities, namely the excess demand for used cars and the excess demand for housing. The results showed several statistically significant correlations between social media communication topic frequency ratios and the excess demand for both used cars and housing. These results provide evidence to support the possibility of using social media communication for detecting socio-economic recovery activities in a disaster-stricken area. Furthermore, the excess demands for two different types of goods (used cars and housing) had different types of correlations with socio-economic recovery activities. More specifically, our study implies that people in the disaster-stricken area started to be active in recovering and restarting their daily-lives as observed in the excess demand for used cars when there were more communications related to recovery and disaster damage among them. Also, during those periods, there tended to be more communication related to going to and supporting the affected area among the non-local population. In contrast, when the local population started to resettle, they might have communicated more opinions about their situations. Furthermore, our results imply that tweets posted by people local and non-local to the disaster-stricken area might have had different types of correlations with the socio-economic recovery activities.

The academic contribution of this study is that we were able to show the potential usefulness of social media for detecting socio-economic recovery activities, which has not been adequately studied among previous related studies. Furthermore, we were able to demonstrate that communication posted by local and non-local populations had different types of correlations with people's activities in the real world. This indicates that when we study social media communication for recovery, different communication patterns among local and non-local populations should be considered.

However, the authors acknowledge that this work is the first of its kind to examine the possibility of using social media data for detecting recovery activities. There are several limitations. This study collected tweets that contained specific words related to the disaster and disaster recovery activities as explained in the Data section and thus, the keywords might have affected the overall findings. In addition, we note that there is a likelihood of there being other intervening variables for topic frequency ratios. Further research is needed to analyze causality

and direct relationships between topic frequency ratios and recovery activities. There is a need to expand the current study by, for example, analyzing the relationships between social media data and other types of recovery activities in the real world, as well as investigating recent large-scale disasters to understand general baselines of disaster recovery activities. Extracting variable communication topics which are beneficial for disaster responders and managers is another important study topic to demonstrate how social media could be used in all the stages of disaster management. Future studies also need to find effective way to distinguish between posts by locals from those by non-locals.

ACKNOWLEDGEMENTS

This study was partially supported by a research grant, "Proto Award.". The author would like to show gratitude to the Proto Corporation for providing various used-car market data and financial support. This study is also partially supported by the Graduate Program for Social ICT Global Creative Leaders (GCL). In addition, the study is supported by Joint Research Program No.823 at CSIC, The University of Tokyo ("Real Estate Database 1999-2016" by At Home Co., Ltd.).

REFERENCES

Alam, F., Ofli, F., Imran, M., and Aupetit, M (2018) A Twitter Tale of Three Hurricanes: Harvey, Irma, and Maria.Proceedings of the 15th International ISCRAM Conference, NY, USA.

Asahi Shimbun. 2011, April 18. Lands Vary in Values in the Disaster-Stricken Areas (in Japanese), p. 9.

Barr, J., Cohen, J. P., and Kim, E (2017) Storm Surges, Informational Shocks, and the Price of Urban Real Estate: An Application to the Case of Hurricane Sandy. Working Papers Rutgers University, Newark 2017-002, Department of Economics, Rutgers University, Newark.

Bica, M., Palen, L., and Bopp, C. (2017) Visual Representations of Disaster. Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing, Portland, Oregon. https://doi.org/10.1145/2998181.2998212

Blei, D. (2012) Probabilistic topic models. Communications of the ACM 55, 77. https://doi.org/10.1145/2133806.2133826

Bloomberg, M. (2013) A Stronger, More Resilient New York. Retrieved from https://www.nycedc.com/resource/stronger-more-resilient-new-york (accessed Dec 8, 2018)

Breuninger, K. (2017) Hurricane Harvey could Cause a Price Surge for Used Cars. CNBC. https://www.cnbc.com/2017/08/30/hurricane-harvey-could-cause-a-price-surge-for-used-cars.html (accessed Jun 20, 2018)

Castillo, C. (2016) Big Crisis Data - Social Media in Disasters and Time-Critical Situations. Cambridge University Press.

Chee, B. (2017) Hurricanes Cause Used Car Prices to Increase. Daily News. http://www.nydailynews.com/autos/street-smarts/hurricanes-car-prices-increase-article-1.3551132 (accessed Jun 20, 2018)

de Albuquerque, J.P., Herfort, B., Brenning, A., Zipf, A. (2015) A Geographic Approach for Combining Social Media and Authoritative Data towards Identifying Useful Information for Disaster Management. International Journal of Geographical Information Science 29. https://doi.org/10.1080/13658816.

Drabek T.E. 1986. The Logic of the Inventory. In: Human System Responses to Disaster (pp.1-20). Springer Series on Environmental Management. Springer, New York, NY

Gruebner, O., Lowe, S.R., Sykora, M., Shankardass, K., Subramanian, S. V., Galea, S., 2017. A Novel Surveillance Approach for Disaster Mental Health. *PloS One*, 12. https://doi.org/10.1371/journal.pone.0181233

Guan, X., Chen, C. (2014) Using Social Media Data to Understand and Assess Disasters. Natural Hazards, 74, 837–850. https://doi.org/10.1007/s11069-014-1217-1

Grace, R., Kropczynski, J., Pezanowski, S., Halse, S., Umar, P., and Tapia, A (2017) Social Triangulation: A new method to identify local citizens using social media and their local information curation behaviors. Proceedings of the 14th ISCRAM Conference, Albi, France.

Haan, M.A., de Boer, H.W. (2010) Has the Internet Eliminated Regional Price Differences? Evidence from the Used Car Market. De Economist 158, 373–386. https://doi.org/10.1007/s10645-010-9151-4

Hallstrom, D. G., and Smith, V. K. (2005) Market Responses to Hurricanes. Journal of Environmental Economics and Management, 50, 3, 541 - 561. doi: https://doi.org/10.1016/j.jeem.2005.05.002

Kelly, S., and Ahmad, K. (2014) Determining Levels of Urgency and Anxiety during a Natural Disaster: Noise,

Affect, and News in Social Media, Proceedings of 9th International Conference on Language Resources and Evaluation, Reykjavik, Iceland.

Kearns, J., Pak, S., and Buhayar, N (2012, Nov. 23) Now Get Ready for a Huge Economic Boost from Hurricane Sandy. Retrieved fromhttps://www.businessinsider.com/economic-boost-from-hurricane-sandy-2012-11

Kibanov, M., Stumme, G., Amin, I., and Lee, J.G. (2017) Mining Social Media to Inform Peatland Fire and Haze Disaster Management. Social Network Analysis and Mining 7. https://doi.org/10.1007/s13278-017-0446-1

Kogan, M., Palen, L., Anderson, K.M. (2015) Think Local, Retweet Global. Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing, Vancouver, Canada. https://doi.org/10.1145/2675133.2675218

Korolov, R., Peabody, J., Lavoie, A., Das, S., Magdon-Ismail, M., Wallace, W. (2015) Actions Are Louder than Words in Social Media. Proceedings of the 2015 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining, Paris, France. https://doi.org/10.1145/2808797.2809376

Kropivnitskaya, Y., Tiampo, K.F., Qin, J., Bauer, M.A. (2017) Real-Time Earthquake Intensity Estimation Using Streaming Data Analysis of Social and Physical Sensors. Pure and Applied Geophysics 174, 2331–2349. https://doi.org/10.1007/s00024-016-1417-6

Kryvasheyeu, Y., Chen, H., Obradovich, N., Moro, E., Van Hentenryck, P., Fowler, J., Cebrian, M. (2016) Rapid Assessment of Disaster Damage using Social Media Activity. Science Advances. https://doi.org/10.1126/sciadv.1500779

Laituri, M., Kodrich, K. (2008) Online Disaster Desponse Community: People as Sensors of High Magnitude Disasters using Internet GIS. Sensors 8, 3037–3055. https://doi.org/10.3390/s8053037

Lang, S., (2017) Expect Used-Car Prices to Skyrocket in the Southeast Post-Hurricane. Car and Driver. https://blog.caranddriver.com/expect-used-car-prices-to-skyrocket-in-the-southeast-post-hurricane/ (accessed Jun 20, 2018)

Martin, Y., Li, Z.L., Cutter, S.L., (2017) Leveraging Twitter to Gauge Evacuation Compliance: Spatiotemporal analysis of Hurricane Matthew. Plos One 12. https://doi.org/10.1371/journal.pone.0181701

McCoy, S. J., and Zhao, X. (2018) A city under water: A Geospatial Analysis of Storm Damage, Changing Risk Perceptions, and Investment in Residential Housing. Journal of the Associ-ation of Environmental and Resource Economists,5, 2, 301-330. doi: 10.1086/695611

McKenzie, R., and Levendis, J (2010) Flood hazards and urban housing markets: The Effects of Katrina on New Orleans. Journal of Real Estate Finance and Economics. doi: 10.1007/s11146-008-9141-3

Musaev, A., Stowers, and Y., Kam., Harnessing Data to Create an Effective Drought Management System (2017) Proceedings of the 15th International ICRAM Conference, NY, USA.

NBC (2014 Oct 29) Anniversary of Superstorm Sandy, October Snowstorm. Retrieved from https://www.nbcconnecticut.com/news/local/Anniversary-of-October-Snowstorm-Super-Storm-Sandy-280815872.html

Nguyen, D.A., Abdelzaher, T., Borbash, S., Dang, X.H., Ganti, R., Singh, A., Srivatsa, M., 2014. On Critical Event Observability using Social Networks: A Disaster Monitoring Perspective. Proceedings of IEEE Military Communications Conference, Baltimore, MD. https://doi.org/10.1109/MILCOM.2014.268

Nikkei Sangyo Shimbun (2011 May 17) Register of Used Cars Increased in the Disaster-Stricken Area. Nikkei Sangyo Shinbun. (in Japanese)

Olteanu, A., Castillo, C., Diaz, F., and Vieweg, S. (2014) CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises. Proceedings of ICWSM the 8th International AAAI Conference on Weblogs and Social Media, Ann Arbor, MI.

Prieto, M., Caemmerer, B., Baltas, G., (2015) Using a Hedonic Price Model to Test Prospect Theory Assertions: The Asymmetrical and Nonlinear Effect of Reliability on Used Car Prices. Journal of Retailing and Consumer Services 22, 206–212. https://doi.org/10.1016/j.jretconser.2014.08.013

Racioppi, D. (2014 Oct 5) New Homes in Demand on Long Beach Island. Re-trieved fromhttps://www.app.com/story/news/local/ocean-county/2014/10/03/lbi-building-boom-sandy/16654755/

Sakaki, T., Okazaki, M., Matsuo, Y. (2010) Earthquake Shakes Twitter users: Real-Time Event Setection by Social Sensors, Proceedings of the 19th International Conference on World Wide Web. Raleigh, North Carolina.

Sakaki, T., Toriumi, F., Uchiyama, K., Matsuo, Y., Shinoda, K., Kazama, K., Kurihara, S., Noda, I. (2013) The Possibility of Social Media Analysis for Disaster Management. Proceedings of Humanitarian Technology

Conference (R10-HTC), 2013 IEEE Region 10.

Sheth, A. (2009) Citizen Sensing, Social Signals, and Enriching Human Experience. IEEE Internet Computing 13, 87–92. https://doi.org/10.1109/MIC.2009.77

Shibuya, Y., and Tanaka, H. (2018a) A Statistical Analysis Between Consumer Behavior and a Social Network Service: A Case Study of Used-Car Demand Following the Great East Japan Earthquake and Tsunami of 2011, The Review of Socionetwork Strategies, 12, 2, 205-236, https://doi.org/10.1007/s12626-018-0025-6

Shibuya, Y., and Tanaka, H. (2018b) Does Sentiment of Social Media Sense Mid-to Long-Term Socio-Economic Disaster Recovery? A Case Study of Hurricane Sandy Focusing on Housing Demand. Proceedings of the 17th international conference of the japanese economic policy association, Kanagawa, Japan.

Shibuya, Y., Tanaka, H. (2018c) Increased Demand for Housing in Disaster-Stricken Areas: A Case of the Great East Japan Earthquake and Tsunami of 2011. mimeo.

Shibuya, Y., Tanaka, H. (2019) How Does a Large-scale Disaster Impact the Used-car Market., International Journal of Economic Policy Studies. 13, 1, 89-117. https://doi.org/10.1007/s42495-018-0003-6

Simmins, J., Haddad, C., Robinson, J. (2014) Social Media in Support of Outage Management Practices. Proceedings of 2014 IEEE PES T&D Conference and Exposition, Chicago, IL.

Starbird, K., Muzny, G., Palen, L. (2012) Learning from the Crowd: Collaborative Filtering Techniques for Identifying on-the-Ground Twitterers during Mass Disruptions. Proceedings of 9th International Conference on ISCRAM, Vancouver, Canada.

Starbird, K., Palen, L. (2010) Pass it on? : Retweeting in Mass Emergency. Proceedings of the 7th International ISCRAM Conference, Seattle, WA.

Su, L., Cacciatore, M., Liang, X., Brossard, D., Scheufele, D., and Xenos, M. (2017) Analyzing public sentiments online: combining human- and computer-based content analysis. Information Communication and Society, 20, 3, 406–427. doi: 10.1080/ 1369118X.2016.1182197

Wang, Y.D., Wang, T., Ye, X.Y., Zhu, J.Q., Lee, J., 2016. Using Social Media for Emergency Response and Urban Sustainability: A Case Study of the 2012 Beijing Rainstorm. Sustainability 8. https://doi.org/10.3390/su8010025

Wendland, J., Ehnis, C., Clarke, R., and Bunker, D (2018) Sydney Siege, December 2014: A Visualisation of a Semantic Social Media Sentiment Analysis. Proceedings of the 15th International ISCRAM Conference, NY, USA.

Yan, Y., Eckle, M., Kuo, C.-L., Herfort, B., Fan, H., and Zipf, A (2017) Monitoring and assess- ing post-disaster tourism recovery using geotagged social media data. ISPRS Interna- tional Journal of Geo-Information, 6, 5, doi: 10.3390/ijgi6050144

Yuan, W., Guan, D., Huh, E.-N., Lee, S., 2013. Harness Human Sensor Networks for Situational Awareness in Disaster Reliefs: A Survey. IETE Technical Review 30.

Zahra, K., Imran, K., Ostermann, F (2018) Understanding Eyewitness Reports on Twitter During Disasters. 2017., Proceedings of the 15th International ISCRAM Conference, NY, USA.

Zhang, N.Y., Chen, H.J., Chen, J.Y., Chen, X. (2016) Social Media Meets Big Urban Data: A Case Study of Urban Waterlogging Analysis. Computational Intelligence and Neuroscience. https://doi.org/10.1155/2016/3264587

CrisisDPS: Crisis Data Processing Services

Firoj Alam*
Qatar Computing Research Institute
Hamad Bin Khalifa University
Doha, Qatar
fialam@hbku.edu.qa

Muhammad Imran
Qatar Computing Research Institute
Hamad Bin Khalifa University
Doha, Qatar
mimran@hbku.edu.qa

Ferda Ofli
Qatar Computing Research Institute
Hamad Bin Khalifa University
Doha, Qatar
fofli@hbku.edu.qa

ABSTRACT

Over the last few years, extensive research has been conducted to develop technologies to support humanitarian aid tasks. However, many technologies are still limited as they require both manual and automatic approaches, and more importantly, are not ready to be integrated into the disaster response workflows. To tackle this limitation, we develop automatic data processing services that are freely and publicly available, and made to be simple, efficient, and accessible to non-experts. Our services take textual messages (e.g., tweets, Facebook posts, SMS) as input to determine (i) which *disaster type* the message belongs to, (ii) whether it is *informative* or not, and (iii) what *type of humanitarian information* it conveys. We built our services upon machine learning classifiers that are obtained from large-scale comparative experiments utilizing both classical and deep learning algorithms. Our services outperform state-of-the-art publicly available tools in terms of classification accuracy.

Keywords

Social media, humanitarian data processing, text classification, application programming interfaces, data processing services.

INTRODUCTION

In the last decade, we have witnessed a significant increase in the use of Information and Communications Technologies (ICT), mobile devices, and sensors during time-critical events such as natural or human-induced disasters (Wattegama 2014; Imran, Castillo, Diaz, et al. 2015). This increase in the number of data sources results in producing more and more data each day. These data sources include social media platforms (e.g., Facebook and Twitter), WhatsApp groups, SMS communications, web blogs, news articles, RSS feeds, and many more. The combination of easy-to-use technologies and data sources generate vast amounts of data at high velocity, i.e., thousands of documents appear each second.

Extracting useful information from these sources is highly important for humanitarian organizations, government agencies, and public administrative authorities to make timely decisions and to launch relief efforts during emergency situations (Starbird et al. 2010; Vieweg, Hughes, et al. 2010). The information needs of these stakeholders vary depending on their role, responsibilities, and the situation they are dealing with (Vieweg, Castillo, et al. 2014). Often extracting such information becomes difficult for non-technical domain experts from these high volume data sources. It is reported in the literature that manual analysis of such high-volume and high-velocity social media data streams is impossible (Hiltz et al. 2014; Ludwig et al. 2015).

*Corresponding author

Dealing with such large data sources and extracting useful information from them involve many challenges such as parsing unstructured and brief content, filtering out irrelevant and noisy content, handling information overload, among others. Over the last few years, many Artificial Intelligence (AI) techniques and computational methods have been proposed to process social media data for disaster response and management. These techniques aim to solve various challenges ranging from information filtering, overload, and categorization to summarization (Castillo 2016; Rudra et al. 2018; Imran, Castillo, Diaz, et al. 2015). In addition, there have been publicly available tools that collect social media data and automatically categorize them during disaster events (Imran, Castillo, Lucas, et al. 2014; Burel, Saif, Fernandez, et al. 2017; Meier 2012; Okolloh 2009). The common features of these systems include classifying tweets, grouping them into clusters, visualizing them into timelines, geotagging them onto maps, and visualizing topics, sentiment, and concepts over time. We elaborate further on these systems in the Related Work section.

In this paper, as an attempt to shed more light in the direction motivated by the aforementioned studies, we develop automatic data processing services to assist both technical and non-technical end-users including crisis managers, officials from formal humanitarian organizations, first responders, volunteering organizations, non-governmental organizations (NGOs), and researchers in the crisis informatics community in their humanitarian tasks. Specifically, we provide the following services, which are also the contributions of this paper:

- **Disaster type classification:** This service aims to determine whether a text message (e.g., a tweet or a Facebook post or an SMS) is about one of the six disaster types, namely *earthquake*, *fire*, *flood*, *hurricane*, *bombing*, and *shooting*.
- **Informativeness classification:** This service determines whether a text message is *informative* for humanitarian aid purposes or not. Informative messages contain useful information for response organizations to plan and launch relief efforts.
- **Humanitarian information type classification:** The aim of this service is to classify whether a text message is about one of the following ten humanitarian information types: *affected individual*, *caution and advice*, *displaced and evacuations*, *donation and volunteering*, *infrastructure and utilities damage*, *injured or dead people*, *missing and found people*, *response efforts*, and *sympathy and support*. More details about these humanitarian information types are given in the later sections.
- **Crisis Data Processing Services (CrisisDPS):** To provide the aforementioned three classification services to end-users, we develop an end-to-end system that offers various RESTful Application Program Interfaces (APIs). Specifically, we provide separate APIs for (i) single item processing and (ii) batch processing in addition to (iii) a file processing service.
- **State-of-the-art classification models:** We develop state-of-the-art supervised machine learning models to support the aforementioned three classification services.

To develop the underlying machine learning models, we have conducted extensive experiments using both classical and deep learning algorithms. The classical algorithms include Naïve Bayes (NB) (McCallum, Nigam, et al. 1998), Support Vector Machines (SVM) (Hearst et al. 1998) and Random Forests (RF) (Liaw, Wiener, et al. 2002) whereas the deep learning algorithms include Convolutional Neural Networks (CNN) (LeCun et al. 1989), and Long Short-Term Memory Neural Networks (LSTM) (Hochreiter and Schmidhuber 1997). We have also collected and combined many publicly available datasets such as CrisisLex[1], CrisisNLP[2], among others. While consolidating these datasets, one of the challenges was the mismatch between class labels across datasets. We manually mapped the mismatches and selected the class labels that can effectively serve humanitarian purposes. More details can be found in the Datasets section. We make all of our services publicly available to potential end-users at no cost.

The rest of the paper is organized as follows. In the next section, we present a literature review. Next, we describe our data processing services. After that, we present the details of the datasets that we used to develop our machine learning models. Then, we present our experiments, results and discussion. Finally, we conclude the paper in the last section.

[1] http://crisislex.org/
[2] http://crisisnlp.qcri.org/

RELATED WORK

There has been significant progress in crisis computing research with a particular focus on mainly facilitating humanitarian organizations in their relief efforts and supporting their decision-making processes. One of the key research activities has been analyzing social media content. There are many studies that leverage social media such as Twitter, Facebook and YouTube for curating, analyzing, and summarizing crisis-related information in order to extract situational awareness and actionable information (Zade et al. 2018; Imran, Castillo, Lucas, et al. 2014; Vieweg, Hughes, et al. 2010; Terpstra et al. 2012; Tsou et al. 2017). Among different social media platforms, Twitter has been used extensively due to the fact that information appears timely and can be accessed and processed effectively, which are the required key features for the humanitarian organizations. Apart from research studies, many systems have been developed over time, some of which are publicly and freely available. We briefly cover some of these research studies and tools in this section.

Below we provide a list of available tools and systems that utilize social media data to extract crisis-related information.

- Ushahidi (Meier 2012; Okolloh 2009)[3]: Ushahidi is a platform that started its journey back in 2008 as a free and open-source platform that allowed interested individuals and groups to create live, interactive maps. Initially, it aimed to visualize post-election messages on a map. Its current functionality includes mapping and visualization tools to create real-time, dynamic, and multifaceted crisis maps. It allows for visualizing how a crisis situation is evolving over time. A notable deployment is the 2010 Haiti earthquake (Goolsby 2010). It is currently providing one-month-free and premium supports to its users.
- TweetTracker (Kumar et al. 2011)[4]: TweetTracker is another application aimed at supporting Humanitarian Aid and Disaster Relief (HADR) responders to monitor and analyze social media content during crisis situations. The functionality of this tool includes analyzing location, real-time trending, data filtering, and historical analysis.
- Tweedr[5]: Tweedr is another tool that aimed to extract actionable information during natural disasters from Twitter. The functionality of the tool includes clustering and classification.
- Artificial Intelligence for Disaster Response (AIDR) (Imran, Castillo, Lucas, et al. 2014)[6]: AIDR is an active system that facilitates users (e.g., humanitarian organizations) to collect tweets during disaster events and create classifiers on-the-fly by annotating incoming Twitter data according to the categories of their own choices. It is freely available with minimal usability effort.
- Twitris (Purohit and Sheth 2013)[7]: Twitris application is also targeted for Twitter content analysis. The functionality of this system includes collecting, aggregating, and analyzing tweets to give deeper insights as well as facilitate the research and development process.
- SensePlace2 (MacEachren et al. 2011)[8]: SensePlace2 application is focused more on extracting spatiotemporal information with analytic capabilities to deal with large volumes of tweets.
- Enhanced Messaging for the Emergency Response Sector (EMERSE) (Caragea et al. 2011): This system has been developed to analyze tweets and SMS messages. The major functionality of this system includes Twitter crawler, machine translation system, and classification modules while also supporting users with an iPhone application.
- Emergency Situation Awareness (ESA) (Yin et al. 2012)[9]: ESA is aimed at enhancing situational awareness with respect to crises induced by natural hazards, particularly earthquakes. They focus on spatio-temporal information and functionalities include event detection, text classification, online clustering, and geotagging.
- Twicident (Abel et al. 2012)[10]: Twicident is a framework and system that automatically track and filter information, which is relevant for real-world incidents or crises.

[3] https://www.ushahidi.com/
[4] http://tweettracker.fulton.asu.edu/
[5] https://github.com/dssg/tweedr/
[6] http://aidr.qcri.org/
[7] http://twitris.knoesis.org/
[8] https://www.geovista.psu.edu/SensePlace2/
[9] https://esa.csiro.au/aus/index.html
[10] http://www.wis.ewi.tudelft.nl/twitcident/

- Pipeline for Post-Crisis Twitter Data Acquisition (Kejriwal and Gu 2018): This is an ongoing effort that aims to develop a system that requires minimal supervision in an active learning framework.
- Crisis Event Extraction Service (CREES) (Burel and Alani 2018)[11]: CREES is an open-source web API to automatically classify social media posts during crisis situations. The system is developed for three different tasks, where the classification models are based on deep learning algorithms. One can deploy the system on their own server to use the API functionality. This system is currently integrated into the Ushahidi platform as part of the COMRADES project[12].
- Botometer (Varol et al. 2017)[13]: Botometer is an application aimed to detect accounts that are controlled by automated tools, termed as social bots. Such an application is important to detect and filter fake or manipulated content on social media.

As for the crisis-related tweet classification research, current literature explores both classical algorithms (e.g., Maximum Entropy, Logistic Regression (LR), Random Forest (RF), Naïve Bayes (NB) classifier, Support Vector Machines (SVM), and Conditional Random Fields (CRFs)) and deep learning techniques (e.g., Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Long Short-term Memory Neural Networks (LSTM)). In (Imran, S. Elbassuoni, et al. 2013; Imran, S. M. Elbassuoni, et al. 2013), authors report different datasets and NB- and CRF-based classifiers to extract actionable information during disaster events. The feature sets used for developing the classifiers include word unigrams, bigrams, Part-of-Speech (POS) tags, among others. In (Nguyen et al. 2017), authors report a comparative study using classical and deep learning-based algorithms, including SVM, LR, RF, and CNN. Their experimental setting also consists of in-domain and out-domain configurations. Across all experimental configurations, CNN outperforms other algorithms. A similar comparative study has been conducted in (Burel, Saif, Fernandez, et al. 2017; Burel and Alani 2018), where the authors explore different types of features. Their study includes three classification tasks such as (i) related *vs.* not-related, (ii) event types, and (iii) information types. Their findings suggest that SVM and CNN provide very competitive results. The study of Aipe et al. 2018 explores CNN with other tweet-centric (e.g., user mentions, hashtags, and their combinations) features. They report results that outperform state-of-the-art results, which used a similar dataset such as CrisisNLP[14]. However, different than our work, they map class labels of CrisisNLP with a set of their own classes. In another study, Neppalli et al. 2018 compare NB, CNN and Recurrent Neural Network (RNN) with different feature combinations and suggest that CNN outperforms the other models. For a more extensive literature review on this subject, we refer the reader to the study conducted by Imran, Castillo, Diaz, et al. 2015.

SYSTEM AND DATA PROCESSING SERVICES

In this work, we present CrisisDPS, a system to process crisis-related data to support multiple humanitarian tasks. The system is developed to facilitate both technical and non-technical users in the domains of crisis informatics and humanitarian aid working at various levels in an organizational hierarchy, e.g., in an Incident-Command System (ICS)[15], Public Information Officers (PIOs), Safety officers, logistics sections, etc. As most humanitarian organizations already have their information systems, our goal is to provide them with ready-to-use data processing services that can be easily integrated into their existing systems, for example, through a new widget backed by one of the CrisisDPS services.

Figure 1 depicts various functionalities of the CrisisDPS system at a high-level. The system mainly provides three types of data processing services, namely (i) disaster type classification, (ii) informativeness classification, and (iii) humanitarian information type classification. We describe each of these services in detail later in this section. Each classification service offers three types of functionality: (i) single-item processing API, (ii) batch processing API, and (iii) file processing service. Furthermore, we also offer a web demo service to test the system online.

Data Processing Services

The three types of data processing services provided by the CrisisDPS system are described below.

1. Disaster type classification: This service aims to classify a given text message into one of the six disaster types, namely, *earthquake*, *fire*, *flood*, *hurricane*, *bombing*, and *shooting*. We also offer a general category called *none*,

[11] https://evhart.github.io/crees/
[12] https://www.comrades-project.eu/
[13] https://botometer.iuni.iu.edu/#!/api
[14] http://crisisnlp.qcri.org/
[15] https://en.wikipedia.org/wiki/Incident_Command_System

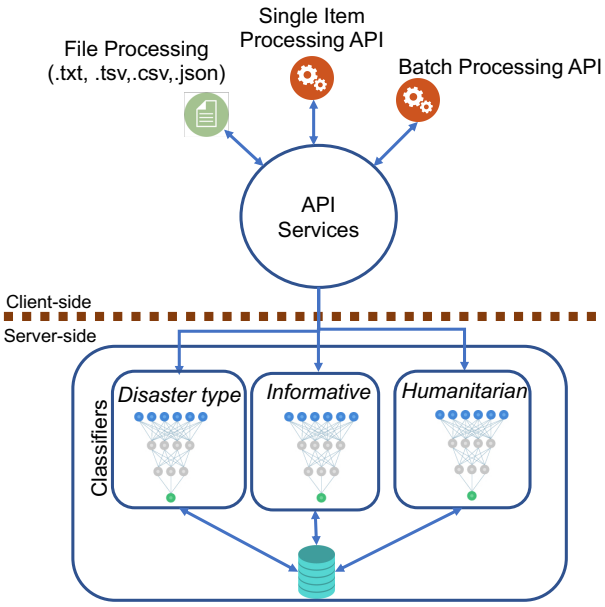


Figure 1. CrisisDPS: Crisis Data Processing Services

which represents everything else that does not belong to any of the six disaster types. The motivation behind this service is to determine whether a message belongs to a particular disaster event or not before dispatching it for further processing. Moreover, this service could be useful for decision-makers in an emergency department who are dealing with multiple disasters at a time helping them to distinguish disaster-specific messages.

2. Informativeness classification: To determine whether a text message contains some useful information for disaster managers or not, we provide the "informativeness" service. Given a text message, the service classifies it either as *informative* or *not informative*. We consider a message as *informative* if it contains some useful information for humanitarian aid; such as disaster-related warnings, reports about injured, dead, or affected people, rescue requests, volunteering or donation offers, reports of damaged houses, roads, etc.

3. Humanitarian information type classification: Given a message is *informative*, which means it contains some useful information for humanitarian aid, the next task is to determine what kind of useful information it conveys. For this purpose, we provide humanitarian information type services. These services correspond to a set of automatic classification services to classify a given text message into one of the ten humanitarian information types described below:

1. *Affected individual:* messages that contain information about affected people due to a disaster event;
2. *Caution and advice:* messages that report warnings, cautions, and give advice to people in the disaster area;
3. *Displaced and evacuations:* messages that report about displaced people or evacuations due to the disaster event;
4. *Donation and volunteering:* messages that request for donations, e.g., food, water, shelter, or offer help or volunteering services;
5. *Infrastructure and utilities damage:* messages that report damages to built structures such as buildings, roads, and bridges;
6. *Injured or dead people:* messages that report injured or dead people due to the disaster event;
7. *Missing and found people:* messages that report missing or found people due to the disaster event;
8. *Requests or needs:* messages that contain requests or urgent needs of affected people;
9. *Response efforts:* messages that report ongoing response efforts by humanitarian organizations, NGOs, and volunteers;
10. *Sympathy and support:* messages that convey thoughts, prayers, sympathy, and support to the victims of the disaster;

11. *Not informative:* messages that do not belong to any of the previous categories or do not contain any useful information.

All three types of classification services are backed by state-of-the-art machine learning classifiers. Specifically, we used supervised machine learning approaches to train the classifiers. More details about these classifiers and the datasets used for training them are given in the next section.

CrisisDPS APIs

The CrisisDPS system provides three types of RESTful APIs for each one of the three classification services. Next, we describe these APIs:

1. Single-item processing API: This programmatic API provides support to classify a single item (e.g., one tweet, or a Facebook message) at a time. Given an item, one can specify one or more classification services to classify it. For example, given a tweet, we want to determine whether it is an *earthquake* or a *hurricane* tweet and whether it contains some useful information or not. Moreover, if it contains useful information, what type of information it contains.

2. Batch processing API: To process more than one items in a batch, the system provides a batch processing programmatic API. For example, given a set of 10,000 tweets, the task is to classify each tweet to determine their informativeness or what humanitarian information they report.

3. File processing service: For non-technical end-users who cannot use our programmatic APIs, we provide a file processing service through a web interface. Figure 2 shows the file uploading interface. Given a file containing a list of messages, tweets, or Facebook posts, this API can classify each message using one or more of the classification services that the end-user selects. Currently, we support four file types: TXT (text files), JSON (JavaScript Object Notation), TSV (Tab-separated values), and CSV (Comma-separated values). Non-technical end-users can easily use the file processing interface to facilitate their humanitarian tasks.

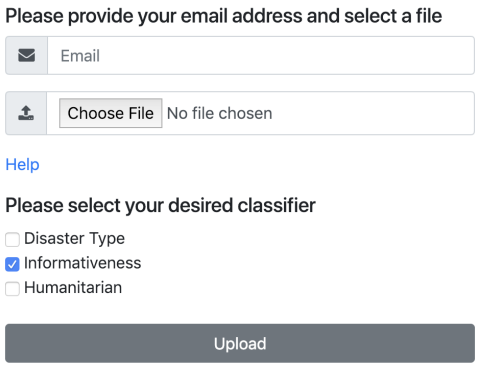


Figure 2. Web interface of the file processing service.

The APIs are implemented in the Java language using the Jersey framework[16], which is an open source and production quality framework for developing RESTful web services in Java. It is combined with Spring[17] and Hibernate[18] frameworks to communicate with databases. The single-item and batch processing APIs only offer programmatic access to use the classification services. However, the file processing API offers a web interface. All the services, APIs, and technical details regarding how to use these APIs with examples are provided on the CrisisDPS website: `http://crisisdps.qcri.org/`. Figure 3 shows a screenshot of the demo page with example tweets and outputs of the selected classification services.

DATASETS

In this work, we use several publicly available datasets including CrisisLex, CrisisNLP, among others. One of the difficulties that arise while combining different datasets is the discrepancies in the class labels. For example, in one dataset, the negative class is labeled as *not-related* while in another one as *not-informative*. Even though these two labels are semantically the same in theory, they are still two different labels in practice. Therefore, for our task

[16] `https://jersey.github.io`. Currently, we use Jersey, in future we might consider to use Spring REST.
[17] `https://spring.io/`
[18] `http://hibernate.org/`

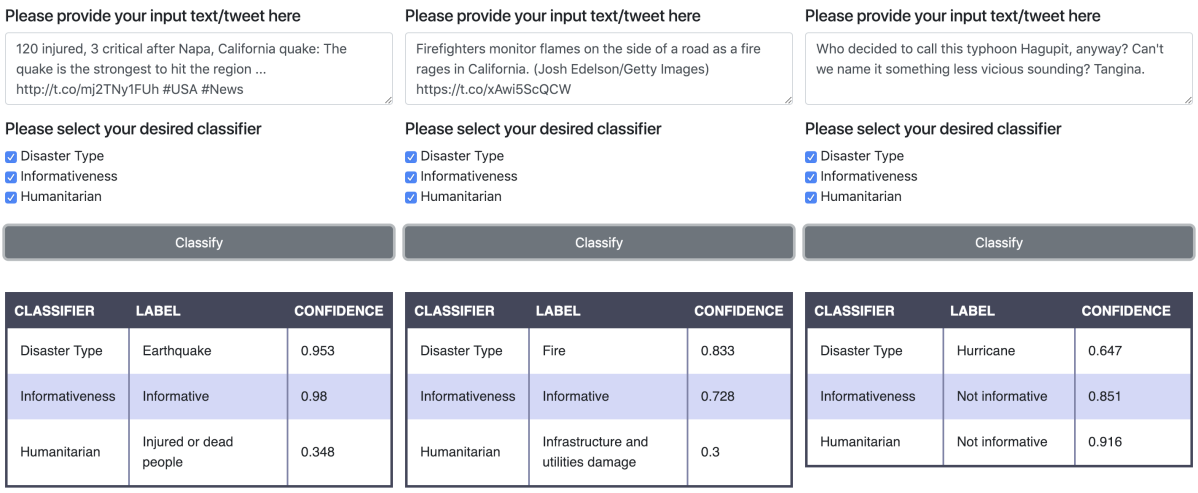


Figure 3. Example usages of the demo page.

we mapped the semantically similar categories to have a unique class label. In addition, we have also filtered out instances with low frequencies and less relevance to the humanitarian tasks at hand. For example, we removed the instances with class labels such as *animal management*, *non-government*, *traditional media*, *terrorism-related*, and *terrorism-related information*. We also removed non-English tweets.

For this study, we aim to develop three different classifiers to serve three different classification tasks: (i) disaster type classification, (ii) informativeness classification, and (iii) humanitarian information type classification. To prepare the data for the informativeness task, we selected all the tweets with *informative/related* class labels and the tweets with humanitarian categories as *informative* and considered the rest as *not-informative*. For the humanitarian information type classification task, we selected data that are labeled with humanitarian categories, which resulted in ten categories as listed in Table 3. In this dataset we have also included instances with *not-informative* label, however, we have only selected a random sample from the whole set of *not-informative* instances. For the disaster type classification task, we selected tweets with the following six disaster types: *bombing*, *earthquake*, *fire*, *flood*, *hurricane*, and *shooting*. In addition, we have also included *none* category as the "background" class. That is, the tweets that do not belong to any of the mentioned six disaster types are considered as belonging to the *none* category.

For the sake of completeness, we provide below brief descriptions of the datasets consolidated for the experiments.

- AIDR[19] is a publicly available system that has been developed to support humanitarian organizations and research community. The system has a functionality that allows users to annotate data while collecting tweets. Over time, AIDR has collected data from many events both labeled and unlabeled. We only selected manually labeled data that are relevant to this study.
- CrisisLex[20] comprises two different datasets, i.e., CrisisLexT26 and CrisisLexT6, that have been used and reported in the literature for crisis informatics research. The CrisisLexT26 is one of the largest datasets consisting of 26 different crisis events that took place in 2012 and 2013 (Olteanu et al. 2014). This dataset was prepared to explore two different crisis dimensions. First dimension is the disaster type (natural *vs.* human-induced), their sub-type (e.g. meteorological, hydrological, etc.), temporal characteristics (instantaneous *vs.* progressive), and geographic spread (focalized *vs.* diffused). The second dimension is the content type in which several type of categories and sub-categories were identified, including informativeness (informative *vs.* not-informative), information type (six different subcategories), and source of information (i.e., an eyewitness, government, NGOs, Business, Media, and Outsiders). The second dataset, CrisisLexT6, consists of six disasters that took place between October 2012 and July 2013 in USA, Canada, and Australia. Crisis keywords and locations have been used during the data collection process (Olteanu et al. 2014). Approximately $10K$ tweets have been annotated using Figure Eight[21] (also known as CrowdFlower) from each crisis event. Annotation of this dataset includes *related vs. not-related*.

[19] http://aidr.qcri.org/
[20] https://crisislex.org
[21] https://www.figure-eight.com/

- CrisisMMD[22] is a multimodal dataset consisting of tweets and associated images (Alam, Ofli, et al. 2018). Tweets have been collected from seven natural disasters that took place in 2017. The annotations include three tasks: (i) *informative vs. not-informative*, (ii) humanitarian categories (eight classes), and (iii) damage severity (three classes). The third annotation task, i.e., damage severity, was applied only on images. The annotation for text and images was run independently for each event using Figure Eight.
- CrisisNLP[23] consists of ~50K tweets, which have been collected from 19 different disasters that took place between 2013 and 2015. The dataset was annotated in two steps. The first set of annotations was obtained using Stand-By-Task-Force (SBTF)[24] volunteers. The second set of annotations was curated using Figure Eight.
- Disaster Response Data[25] contain 30K tweets collected during disasters such as an earthquake in Haiti, 2010; an earthquake in Chile, 2010; floods in Pakistan, 2010; Hurricane Sandy in USA, 2012, and news articles. The annotations include 36 different categories.
- Disasters on Social Media[26] dataset consists of 10K tweets collected and annotated with labels *related* vs. *not-related* to the disasters.
- SWDM[27] consists of two data collections. The Joplin collection contains tweets collected during the tornado that struck Joplin, Missouri on May 22, 2011. The Sandy collection contains tweets collected during Hurricane Sandy, that hit Northeastern US on Oct 29, 2012. The Joplin dataset consists of 4,400 labeled instances and the Sandy dataset consists of 2,000 labeled instances (Imran, S. Elbassuoni, et al. 2013).

After consolidating data from all these collections, we prepared three datasets for three different classification tasks. Tables 2, 3 and 1 present the class distributions of our datasets for disaster type, informativeness, and humanitarian information type, respectively. We split each dataset into three subsets using 70%, 10% and 20% as training, development and test, respectively. The training set is used to learn the model, the development (dev) set is used for parameter tuning, and the test set is used for the model evaluation.

Table 1. Data split for disaster type classification.

Classes	Train (70%)	Dev (10%)	Test (20%)	Total	Class Dist.
Bombing	378	53	109	540	0.007
Earthquake	9,088	1,285	2,611	12,984	0.162
Fire	2,185	309	628	3,122	0.039
Flood	10,156	1,436	2,917	14,509	0.181
Hurricane	23,491	3,322	6,746	33,559	0.418
Shooting	527	74	153	754	0.009
None	10,306	1,457	2,961	14,724	0.184
Total	56,131	7,936	16,125	80,192	

Table 2. Data split for informativeness classification.

Classes	Train (70%)	Dev (10%)	Test (20%)	Total	Class Dist.
Informative	131,028	18,531	37,624	187,183	0.639
Not-informative	74,104	10,480	21,280	105,864	0.361
Total	205,132	29,011	58,904	293,047	

EXPERIMENTS, RESULTS, AND DISCUSSION

In this section, we describe the details of our extensive experiments, report our results, and provide a discussion.

[22] http://crisisnlp.qcri.org/
[23] http://crisisnlp.qcri.org/
[24] www.standbytaskforce.org
[25] https://www.figure-eight.com/dataset/combined-disaster-response-data/
[26] https://data.world/crowdflower/disasters-on-social-media
[27] http://crisisnlp.qcri.org/

Table 3. Data split for humanitarian information type classification.

Classes	Train (70%)	Dev (10%)	Test (20%)	Total	Class Dist.
Affected individual	2,536	358	729	3,623	0.073
Caution and advice	2,644	374	760	3,778	0.076
Displaced and evacuations	519	73	150	742	0.015
Donation and volunteering	5,677	802	1,631	8,110	0.163
Infrastructure and utilities damage	4,619	653	1,327	6,599	0.133
Injured or dead people	2,771	392	796	3,959	0.080
Missing and found people	460	65	133	658	0.013
Requests or needs	5,088	719	1,462	7,269	0.146
Response efforts	1,857	263	534	2,654	0.053
Sympathy and support	4,438	627	1,275	6,340	0.127
Not-informative	4,200	594	1,206	6,000	0.121
Total	34,809	4,920	10,003	49,732	

Preprocessing

The tweet texts are noisy, usually consisting of many symbols, emoticons, and invisible characters. Therefore, we preprocessed them to use in classification experiments. The preprocessing part includes removal of stop words, non-ASCII characters, punctuations (replaced with whitespace), numbers, URLs, and hashtags.

Classification Experiments

For this study, we have conducted classification experiments using both classical and deep learning algorithms. As for the classical models, we used the three most popular machine learning algorithms, i.e., (i) Naïve Bayes (NB), (ii) Random Forest (RF), and (iii) Support Vector Machines (SVM). The usefulness of these algorithms have been reported in several studies in crisis computing literature (Burel, Saif, and Alani 2017; Neppalli et al. 2018; Imran, Mitra, et al. 2016). As for the deep learning algorithms, we used a Convolutional Neural Network (CNN), which has also been reported as successful in many studies for disaster tweets classification (Nguyen et al. 2017; Burel and Alani 2018).

- The NB algorithm (McCallum, Nigam, et al. 1998) is a simple probabilistic method that calculates a set of probabilities by counting the frequency and combinations of values in a given dataset. The algorithm uses Bayes theorem and stands on the assumption that all attributes are independent given the value of the class variable, which is rarely true in real applications, but it still performs well and learns rapidly in many supervised tasks (Neppalli et al. 2018; Imran, Mitra, et al. 2016).
- The SVM algorithm (Platt 1998) is based on the Structural Risk Minimization principle from computational learning theory. The algorithm is established as universal learners and well-known for its ability to learn independently of the dimensionality of the feature space. These properties of the algorithm make it one of the most popular supervised classification methods.
- Unlike the previous two classical algorithms, the RF algorithm (Liaw, Wiener, et al. 2002) is an ensemble learning algorithm, comprising multiple decision trees where each tree contributes to the classification decision with a single vote. A final class label is assigned based on majority voting. RF reduces variances in the classification by randomizing features and training instances.
- In Figure 4, we present the architecture of our CNN model. The input to the network is a tweet $\mathbf{t} = (w_1, \ldots, w_n)$ containing words each coming from a finite vocabulary $\mathcal{V}$ that we obtained from our training dataset. The first layer of the network maps each of these words into a distributed representation $\mathbb{R}^d$ by looking up a shared embedding matrix $E \in \mathbb{R}^{|\mathcal{V}| \times d}$. We initialized E using a publicly available pre-trained embedding model designed using disaster related tweets[28] (Alam, Joty, et al. 2018). The output of the look-up layer is a matrix $X \in \mathbb{R}^{n \times d}$, which is passed through a number of convolutional and pooling layers to learn higher-level feature representations. A convolution operation applies a *filter* $\mathbf{u} \in \mathbb{R}^{k.d}$ to a window of k vectors to produce a new feature $h_t = f(\mathbf{u}.X_{t:t+k-1})$, where $X_{t:t+k-1}$ is the concatenation of k look-up vectors, and f is a nonlinear

[28] http://crisisnlp.qcri.org/data/lrec2016/crisisNLP_word2vec_model_v1.2.zip

activation. We used rectified linear units (ReLU) as a nonlinear activation function. We apply this filter to each possible k-length windows in X to generate a *feature map*, $\mathbf{h}^j = [h_1, \ldots, h_{n+k-1}]$. This process is repeated N times with N different filters to get N different feature maps. We then apply a *max-pooling* operation, $\mathbf{m} = [\mu_p(\mathbf{h}^1), \cdots, \mu_p(\mathbf{h}^N)]$, where $\mu_p(\mathbf{h}^j)$ refers to the max operation applied to each window of p features in the feature map $\mathbf{h}^i$. Intuitively, the convolution operation composes local features into higher-level representations in the feature maps, and max-pooling extracts the most important aspects of each feature map while reducing the output dimensionality. Since each convolution-pooling operation is performed independently, the features extracted become invariant in order. In order to incorporate order information between the pooled features, we use a fully-connected (dense) layer $\mathbf{z} = f(V\mathbf{m})$, where V is the weight matrix. From which we have another dense layer $\mathbf{z}_c = f(V_c\mathbf{z})$ where V_c is the corresponding weight matrix. The activations $\mathbf{z}_c$ are used for classification. Formally, the classification layer defines a Softmax

$$p(y = k|\mathbf{t}, \theta) = \frac{\exp\left(W_k^T \mathbf{z}_c\right)}{\sum_{k'} \exp\left(W_{k'}^T \mathbf{z}_c\right)} \tag{1}$$

where W_k are the class weights and $\theta = \{V, V_c, W\}$ defines the relevant parameters.

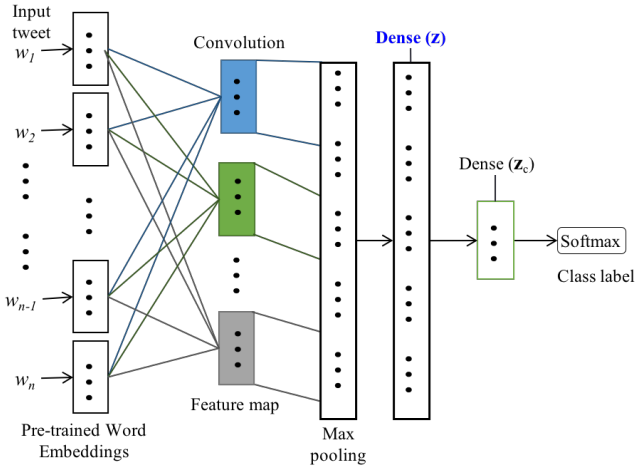


Figure 4. The architecture of the CNN.

To train the classifiers using these classical algorithms, we converted the preprocessed tweets into bag-of-ngrams vectors weighted with logarithmic term frequencies (tf) multiplied with inverse document frequencies (idf), as shown in Equation 2.

$$tf \times idf = log(1 + f_{ij}) \times log\left(\frac{\text{number of tweets}}{\text{number of tweets that include word i}}\right) \tag{2}$$

where f_{ij} is the frequency for word i in tweet j. To take advantage of the contextual benefits of n-grams, we extracted tri-gram features. Because this resulted in a large dictionary and we filtered out lower frequency features by preserving $40K$ most frequent n-grams. For the experiments with SVM and its linear kernel we tune the c parameter, and with RF we tune the number of trees on the development set.

We trained the CNN models using the Adadelta optimizer (Zeiler 2012). The learning rate was set to 0.01 when optimizing on the classification loss. The maximum number of epochs was set to 1,000, and dropout (Srivastava et al. 2014) rate of 0.02 was used to avoid overfitting. We did *early stopping* based on the accuracy on the development set with a patience of 50. We used 100, 150, 200, and 250 filters with the corresponding window size of 2, 3, 4, and 5 respectively. We used a pooling length of 2. We did not tune any hyperparameter (e.g., the size of hidden layers, filter size, dropout rate) in the experimental setting. We also applied batch normalization due to its success reported in the literature (Ioffe and Szegedy 2015).

Table 4 summarizes the results obtained by different classification algorithms described above. We provide weighted average precision (P), recall (R) and F1-measure (F1) for each task. The rationale behind choosing the weighted metric is that it takes into account the class imbalance problem. The performance of the NB model is lower than other models. Whereas RF and SVM model provides competitive results across different tasks. For the informativeness task RF outperforms SVM, whereas for humanitarian and disaster type tasks SVM outperforms RF. We obtain higher results consistently across all the tasks using CNN.

Table 4. Classification performance comparison of all the classifiers on three different tasks.

	Disaster Type				Informativeness				Humanitarian			
	Acc	**P**	**R**	**F1**	**Acc**	**P**	**R**	**F1**	**Acc**	**P**	**R**	**F1**
NB	0.73	0.82	0.73	0.71	0.85	0.85	0.85	0.85	0.65	0.77	0.65	0.69
SVM	0.93	0.93	0.93	**0.93**	0.90	0.90	0.90	0.90	0.78	0.78	0.78	**0.78**
RF	0.91	0.92	0.91	0.91	0.93	0.93	0.93	**0.93**	0.76	0.77	0.76	0.76
CNN	0.93	0.93	0.93	**0.93**	0.93	0.93	0.93	**0.93**	0.78	0.78	0.78	**0.78**

Table 5. Mapping of the class labels between CREES and CrisisDPS.

Disaster Type

CREES	**CrisisDPS**
Bombings	*Bombing*
Collapse	*None*
Crash	*None*
Derailment	*None*
Earthquake	*Earthquake*
Explosion	*None*
Fire	*Fire*
Floods	*Flood*
Haze	*None*
Meteorite	*None*
None	*None*
Shootings	*Shooting*
Typhoon	*Hurricane*
Wildfire	*Fire*

Informativeness

CREES	**CrisisDPS**
Related	*Informative*
Not-related	*Not-informative*

Humanitarian Information Type

CREES	**CrisisDPS**
Affected individuals	*Affected individual*
Caution and advice	*Caution and advice*
Donations and volunteering	*Donation and volunteering*
Infrastructure and utilities	*Infrastructure and utilities damage*
Not applicable	*Not-informative*
Not labeled	X
Other useful information	X
Sympathy and support	*Sympathy and support*

X indicates the CREES class labels that were not considered in this work.

Baseline Comparisons

To compute the baseline results we used the publicly available deep learning models[29] reported in (Burel and Alani 2018). The CREES API consists of three models for three different tasks such as (i) related *vs.* not-related, (ii) event type (11 class labels), and (iii) information type (i.e., humanitarian categories). To evaluate the performance of the CREES models and have the baseline results for our study, we used our test set and mapped the class labels as shown in Table 5.

Table 6. Comparative results for disaster type classification.

	CREES			CrisisDPS		
Classes	**P**	**R**	**F1**	**P**	**R**	**F1**
Bombing	0.54	0.83	0.66	0.94	0.93	**0.94**
Earthquake	0.96	0.66	0.78	0.92	0.94	**0.93**
Fire	0.85	0.88	0.86	0.95	0.93	**0.94**
Flood	0.35	0.94	0.51	0.94	0.93	**0.93**
Hurricane	0.98	0.1	0.18	0.93	0.96	**0.95**
Shooting	0.97	0.96	0.97	1.00	0.99	**0.99**
None	0.45	0.73	0.55	0.94	0.87	**0.91**
W/Avg	0.76	0.50	0.45	0.93	0.93	**0.93**

In Tables 6, 7, and 8, we provide class-wise precision (P), recall (R) and F1-measure (F1) as well as their weighted average both for the baseline CREES models and the proposed CrisisDPS models. We observed that there is a significant performance difference across all classification tasks compared to the results reported in the study of CREES (Burel and Alani 2018). For the humanitarian categories, the CREES model is designed using eight class

[29] https://github.com/evhart/crees

labels, whereas our model is designed with eleven class labels. Hence, in Table 8, we do not have results for some class labels using the CREES model. In Table 8, the weighted average results for CrisisDPS are computed using only the subset of categories available in CREES for a fair comparison.

Table 7. Comparative results for informativeness classification.

	CREES			CrisisDPS		
Classes	**P**	**R**	**F1**	**P**	**R**	**F1**
Informative	0.88	0.86	0.87	0.95	0.95	0.95
Not-informative	0.76	0.79	0.78	0.91	0.90	0.91
W/Avg	0.84	0.84	**0.84**	0.93	0.93	**0.93**

Table 8. Comparative results for humanitarian information type classification.

	CREES			CrisisDPS		
Classes	**P**	**R**	**F1**	**P**	**R**	**F1**
Affected individual	0.28	0.70	0.40	0.72	0.69	**0.70**
Caution and advice	0.51	0.58	0.54	0.72	0.74	**0.73**
Displaced and evacuations	-	-	-	0.65	0.54	0.59
Donation and volunteering	0.54	0.70	0.61	0.77	0.80	**0.79**
Infrastructure and utilities damage	0.78	0.32	0.45	0.77	0.75	**0.76**
Injured or dead people	-	-	-	0.86	0.86	0.86
Missing and found people	-	-	-	0.67	0.44	0.53
Requests or needs	-	-	-	0.86	0.89	0.88
Response efforts	-	-	-	0.75	0.77	0.76
Sympathy and support	0.47	0.84	0.60	0.80	0.79	**0.80**
Not-informative	0.87	0.02	0.04	0.74	0.74	**0.74**
W/Avg	0.41	0.36	0.31	0.76*	0.76*	**0.76***

* computed using only the subset of categories available in CREES.

Discussion and Future Directions

We have provided comparative results between classical and deep learning models. We have also compared the performance of our best model with publicly available models. Even though we have only provided an end-to-end comparison with the CREES models in this study, our models also outperform some other existing works such as (Nguyen et al. 2017; Neppalli et al. 2018).

To estimate the load of our system, we plan to have an extensive study in the future and plan to deploy the system accordingly. We also plan to make the system more scalable. Other future work includes integrating image processing modules such as finding an informative image, identifying their humanitarian information type, and assessing the damage content.

Even though we developed the classification models using only social media data such as tweets, the CrisisDPS system can easily be extended by integrating other models. The benefit of CrisisDPS is that it provides services with RESTful APIs by taking the burden of running them on a local server. Such facilities can be helpful for humanitarian organizations and crisis computing research community to develop their own applications and systems using our services. Our goal is to make the CrisisDPS freely available, however, an authentication system will be implemented to control the rate limit (e.g., data processing limit per day per user) and to prevent potential abuse of the system so that every user can get equal benefit from the system.

CONCLUSIONS

In this study, we introduced CrisisDPS, a system for automatic data processing services, which comprises state-of-the-art information classification models that enable humanitarian organizations and crisis informatics research community to develop their own applications and systems. Currently, CrisisDPS provide services that can facilitate three important humanitarian tasks: (i) determine which disaster type a text message belongs to, (ii) determine

whether the message is informative for disaster response, and (iii) determine whether it manifests about any humanitarian information type. Such information is highly relevant for humanitarian organizations if processed timely and effectively. The classification models that we developed for these three tasks outperform existing publicly available models. We aim to provide as much flexibility as possible to the end-users who are willing to use our system. For example, our current implementation supports single item and batch processing through different APIs, file processing for different formats, and an online demo page for quick testing purposes. We plan to improve our services based on a thorough user study in the future. We also plan to make the system more scalable and extend it with automatic image processing capabilities.

REFERENCES

Abel, F., Hauff, C., Houben, G.-J., Stronkman, R., and Tao, K. (2012). "Semantics+ filtering+ search= twitcident. exploring information in social web streams". In: *Proc. of the 23rd ACM HT conference*. ACM, pp. 285–294.

Aipe, A., Mukuntha, N., Ekbal, A., and Kurohashi, S. (2018). "Deep Learning Approach towards Multi-label Classification of Crisis Related Tweets". In: *Proc. of the 15th ISCRAM, 2018*.

Alam, F., Joty, S. R., and Imran, M. (2018). "Graph Based Semi-supervised Learning with Convolution Neural Networks to Classify Crisis Related Tweets". In: *Proc. of the 12th ICWSM, 2018*. AAAI press.

Alam, F., Ofli, F., and Imran, M. (2018). "CrisisMMD: Multimodal twitter datasets from natural disasters". English. In: *Proc. of the 12th ICWSM, 2018*. AAAI press, pp. 465–473.

Burel, G. and Alani, H. (2018). "Crisis Event Extraction Service (CREES)-Automatic Detection and Classification of Crisis-related Content on Social Media". In: *Proc. of the 15th ISCRAM, 2018*.

Burel, G., Saif, H., and Alani, H. (2017). "Semantic wide and deep learning for detecting crisis-information categories on social media". In: *International Semantic Web Conference*. Springer, pp. 138–155.

Burel, G., Saif, H., Fernandez, M., and Alani, H. (2017). "On Semantics and Deep Learning for Event Detection in Crisis Situations". In: *Workshop on Semantic Deep Learning (SemDeep), at ESWC 2017*.

Caragea, C., McNeese, N., Jaiswal, A., Traylor, G., Kim, H.-W., Mitra, P., Wu, D., Tapia, A. H., Giles, L., Jansen, B. J., et al. (2011). "Classifying text messages for the haiti earthquake". In: *Proc. of the 8th ISCRAM, 2011*.

Castillo, C. (2016). *Big Crisis Data*. Cambridge, UK: Cambridge University Press.

Goolsby, R. (2010). "Social media as crisis platform: The future of community maps/crisis maps". In: *ACM Transactions on Intelligent Systems and Technology (TIST)* 1.1, p. 7.

Hearst, M. A., Dumais, S. T., Osuna, E., Platt, J., and Scholkopf, B. (1998). "Support vector machines". In: *IEEE Intelligent Systems and their applications* 13.4, pp. 18–28.

Hiltz, S. R., Kushma, J., and Plotnick, L. (2014). "Use of Social Media by U.S. Public Sector Emergency Managers: Barriers and Wish Lists". In: University Park, Pennsylvania, USA.

Hochreiter, S. and Schmidhuber, J. (1997). "Long short-term memory". In: *Neural computation* 9.8, pp. 1735–1780.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015). "Processing social media messages in mass emergency: A survey". In: *ACM Computing Surveys* 47.4, p. 67.

Imran, M., Castillo, C., Lucas, J., Meier, P., and Vieweg, S. (2014). "AIDR: Artificial intelligence for disaster response". In: *Proc. of the ACM Conference on WWW*, pp. 159–162.

Imran, M., Elbassuoni, S. M., Castillo, C., Diaz, F., and Meier, P. (2013). "Extracting information nuggets from disaster-related messages in social media". In: *Proc. of the 12th ISCRAM*.

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., and Meier, P. (2013). "Practical extraction of disaster-relevant information from social media". In: *Proc. of the 22nd WWW*. ACM, pp. 1021–1024.

Imran, M., Mitra, P., and Castillo, C. (2016). "Twitter as a Lifeline: Human-annotated Twitter Corpora for NLP of Crisis-related Messages". In: *Proc. of the LREC, 2016*. Paris, France: ELRA.

Ioffe, S. and Szegedy, C. (2015). "Batch normalization: Accelerating deep network training by reducing internal covariate shift". In: *arXiv preprint arXiv:1502.03167*.

Kejriwal, M. and Gu, Y. (2018). "A Pipeline for Post-Crisis Twitter Data Acquisition". In: *arXiv preprint arXiv:1801.05881*.

Kumar, S., Barbier, G., Abbasi, M. A., and Liu, H. (2011). "TweetTracker: An Analysis Tool for Humanitarian and Disaster Relief." In: *Proc. of the 5th ICWSM, 2011*. AAAI press.

LeCun, Y., Boser, B., Denker, J. S., Henderson, D., Howard, R. E., Hubbard, W., and Jackel, L. D. (1989). "Backpropagation applied to handwritten zip code recognition". In: *Neural computation* 1.4, pp. 541–551.

Liaw, A., Wiener, M., et al. (2002). "Classification and regression by Random Forest". In: *R news* 2.3, pp. 18–22.

Ludwig, T., Reuter, C., Siebigteroth, T., and Pipek, V. (2015). "CrowdMonitor: Mobile crowd sensing for assessing physical and digital activities of citizens during emergencies". In: *Proc. of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, pp. 4083–4092.

MacEachren, A. M., Jaiswal, A., Robinson, A. C., Pezanowski, S., Savelyev, A., Mitra, P., Zhang, X., and Blanford, J. (2011). "Senseplace2: Geotwitter analytics support for situational awareness". In: *Proc. of the IEEE conference on VAST, 2011*. IEEE, pp. 181–190.

McCallum, A., Nigam, K., et al. (1998). "A comparison of event models for naive bayes text classification". In: *AAAI-98 workshop on learning for text categorization*. Vol. 752. 1. Citeseer, pp. 41–48.

Meier, P. (2012). "Crisis mapping in action: How open source software and global volunteer networks are changing the world, one map at a time". In: *Journal of Map & Geography Libraries* 8.2, pp. 89–100.

Neppalli, V. K., Caragea, C., and Caragea, D. (2018). "Deep Neural Networks versus Naïve Bayes Classifiers for Identifying Informative Tweets during Disasters". In: *Proc. of the 15th ISCRAM, 2018*.

Nguyen, D. T., Al-Mannai, K., Joty, S. R., Sajjad, H., Imran, M., and Mitra, P. (2017). "Robust Classification of Crisis-Related Data on Social Networks Using Convolutional Neural Networks." In: *Proc. of the 11th ICWSM, 2017*. AAAI press, pp. 632–635.

Okolloh, O. (2009). "Ushahidi, or 'testimony': Web 2.0 tools for crowdsourcing crisis information". In: *Participatory learning and action* 59.1, pp. 65–70.

Olteanu, A., Castillo, C., Diaz, F., and Vieweg, S. (2014). "CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises." In: *Proc. of the 8th ICWSM, 2014*. AAAI press.

Platt, J. (1998). *Sequential minimal optimization: A fast algorithm for training support vector machines*. Tech. rep. Redmond, USA.: Microsoft.

Purohit, H. and Sheth, A. P. (2013). "Twitris v3: From Citizen Sensing to Analysis, Coordination and Action." In: *Proc. of the 7th ICWSM, 2013*. AAAI press.

Rudra, K., Goyal, P., Ganguly, N., Mitra, P., and Imran, M. (2018). "Identifying sub-events and summarizing disaster-related information from microblogs". In: *The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval*. ACM, pp. 265–274.

Srivastava, N., Hinton, G. E., Krizhevsky, A., Sutskever, I., and Salakhutdinov, R. (2014). "Dropout: a simple way to prevent neural networks from overfitting." In: *Journal of MLR* 15.1, pp. 1929–1958.

Starbird, K., Palen, L., Hughes, A. L., and Vieweg, S. (2010). "Chatter on the red: what hazards threat reveals about the social life of microblogged information". In: *ACM Conference on Computer Supported Cooperative Work*, pp. 241–250.

Terpstra, T., De Vries, A., Stronkman, R., and Paradies, G. (2012). *Towards a realtime Twitter analysis during crises for operational crisis management*. British Columbia, Canada: Simon Fraser University Burnaby.

Tsou, M.-H., Jung, C.-T., Allen, C., Yang, J.-A., Han, S. Y., Spitzberg, B. H., and Dozier, J. (2017). "Building a Real-Time Geo-Targeted Event Observation (Geo) Viewer for Disaster Management and Situation Awareness". In: *Proc. of the International Cartographic Conference*. Springer, pp. 85–98.

Varol, O., Ferrara, E., Davis, C., Menczer, F., and Flammini, A. (2017). "Online Human-Bot Interactions: Detection, Estimation, and Characterization". In: *Proc. of the 11th ICWSM, 2018*. AAAI press.

Vieweg, S., Castillo, C., and Imran, M. (2014). "Integrating social media communications into the rapid assessment of sudden onset disasters". In: *International Conference on Social Informatics*. Springer, pp. 444–461.

Vieweg, S., Hughes, A. L., Starbird, K., and Palen, L. (2010). "Microblogging during two natural hazards events: what twitter may contribute to situational awareness". In: *SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 1079–1088.

Wattegama, C. (2014). "ICT for disaster management". In: *UNDP-APDIP*.

Yin, J., Lampert, A., Cameron, M., Robinson, B., and Power, R. (2012). "Using social media to enhance emergency situation awareness". In: *IEEE Intelligent Systems* 27.6, pp. 52–59.

Zade, H., Shah, K., Rangarajan, V., Kshirsagar, P., Imran, M., and Starbird, K. (2018). "From Situational Awareness to Actionability: Towards Improving the Utility of Social Media Data for Crisis Response". In: *Proceedings of the ACM on Human-Computer Interaction* 2.CSCW, p. 195.

Zeiler, M. D. (2012). "ADADELTA: an adaptive learning rate method". In: *arXiv preprint arXiv:1212.5701*.

Integrating Social Media in Emergency Dispatch via Distributed Sensemaking

Rob Grace
Penn State University
wrg123@ist.psu.edu

Shane Halse
Penn State University
seh297@ist.psu.edu

Jess Kropczynski
University of Cincinnati
jess.kropczynski@uc.edu

Andrea Tapia
Penn State University
atapia@ist.psu.edu

Fred Fonseca
Penn State University
ffonseca@ist.psu.edu

ABSTRACT

Emergency dispatchers typically answer 911 calls and relay information to first responders; however, new workflows arise when social media analysts are included in emergency dispatch work. In this study we examine emergency dispatch workflows as distributed sensemaking processes performed among 911 call takers, dispatchers, and social media analysts during simulated emergency dispatch operations. In active shooter and water rescue scenarios, emergency dispatch teams including call takers, dispatchers, and social media analysts make sense of unfolding events by analyzing, aggregating, and synthesizing information provided by 911 callers and social media users during each scenario. Findings from the simulations inform design requirements for social media analysis tools that can help analysts detect, seek, and analyze information posted on social media during a crisis, and protocols for coordinating analysts' sensemaking activities with those of 911 call takers and dispatchers in reconfigured emergency dispatch workflows.

Keywords

sensemaking, emergency dispatch, social media, simulation

INTRODUCTION: INTEGRATING SOCIAL MEDIA IN NEXT-GENERATION EMERGENCY DISPATCH

When someone dials an emergency telephone number like 911, they begin an information processing task that culminates when a first responder arrives at the scene of an emergency. While information dispatched to first responders (i.e. fire, medical, police) constitute the output of this task, the inputs, traditionally provided by 911 callers, are increasing in volume and variety. The development of Next-Generation 911 infrastructure will soon allow people to call, text, or use web-based applications to contact emergency dispatch centers (Holland, 2018), known as Public-Safety Answering-Points (PSAPs), which, increasingly, seek to detect emergencies and gather situational awareness information using data collected from physical and social sensors, including social media.

In the new, data-rich PSAP, the work of emergency dispatchers coordinating information flows between citizens and first responders— the throughput of emergency response— becomes much more complex. Anticipated by data analytics in policing beginning with early statistical tools such as CompStat in New York City and, more recently, dedicated Strategic Decision Support Centers in Chicago (Smith, 2018), PSAPs are beginning to process an array of data inputs from physical (e.g. cameras, license plate readers, and gunshot detectors) and social (e.g. 911 calls and social media) sensors, and digital records databases (e.g. arrests, complaints, summonses, and firearm registries) (Levine & Tisch, 2014). Consequently, PSAPs are transforming from reactive call centers to proactive data analytics and coordination hubs providing first responders with real-time information before, during, and after emergencies.

In this regard, integrating social media in emergency dispatch operations presents PSAPs with distinct opportunities. PSAPs can use social media to disseminate warnings and other emergency-related information during crises when call processing may be disrupted or delayed due to high-call volumes. Utilized for situational awareness, social media can alert PSAP staff to developing emergencies and augment information provided by 911 callers (Grace, Kropczynski, & Tapia, 2018). While prior studies examine the coordination of emergency

dispatch work surrounding traditional call taking and dispatch activities (Furniss & Blandford, 2006; Norri-Sederholm, Seppälä, Saranto, & Paakkonen, 2016; Preusse & Gipson, 2016), Boersma et al. (2016) describe the novel trial of Twitcident, a web-based system for filtering, searching, and analyzing social media data within Dutch emergency dispatch centers. The trial proved "disappointing" as dispatchers had trouble selecting search terms to filter social media data as well as difficulty integrating information from social media and existing information sources. As a result, the system often provided redundant information that did not enhance emergency dispatch operations (p. 243-4). The findings of Boersma et al. suggest that integrating social media in emergency dispatch requires, first, developing social media analysis tools that can provide dispatchers-turned-analysts with relevant information and, second, integrating social media monitoring within emergency dispatch workflows already responsible for gathering and integrating information from multiple 911 callers.

Consequently, this study examines how PSAPs can incorporate social media analysts and social media analysis tools within workflows integrating information from social media and 911 calls during an emergency. We approach these workflows as distributed sensemaking processes performed among 911 call takers, dispatchers, and social media analysts. Whereas prior studies examine sensemaking among social media users posting and engaging social media content during a crisis (Mirbabaie & Zapatka, 2017; Stieglitz, Mirbabaie, & Milde, 2018), or among officials gathering information only from emergency callers (McMaster, Baber, & Duffy, 2012), this study explores how emergency dispatch teams make sense of events during an emergency by analyzing, aggregating, and synthesizing information from social media and 911 calls to address the evolving situational awareness needs of first responders. Conducting simulations to explore new workflows and distributed sensemaking processes of emergency dispatch teams in active shooter and water rescue scenarios, the findings of this study inform design requirements for social media analysis tools that can help analysts detect, seek, and analyze information posted on social media during a crisis, and protocols for coordinating analysts' sensemaking activities with those of 911 call takers and dispatchers in reconfigured emergency dispatch workflows.

THEORY: EMERGENCY DISPATCH AS DISTRIBUTED SENSEMAKING

Following Klein et al. (2007), we approach sensemaking as "a deliberate effort to understand events" (p. 114). Figure 1 illustrates the Data-Frame model of sensemaking, an iterative process of modifying or replacing the current understanding of a situation or "frame." According to Klein et al. (2007), a frame is "an explanatory structure that defines entities by describing their relationship to other entities" (p. 118). Frames can take the form of stories, maps, or scripts (p. 118). Stories provide chronological orderings and causal relationships, while maps provide spatial arrangements from which routes to landmarks can be inferred. Scripts, in contrast, outline cooperative roles and coordinate action by meshing together actors' activities. Importantly, frames both explain a situation and guide information seeking: "a frame is a structure for accounting for the data and guiding the search for more data" (p. 118).

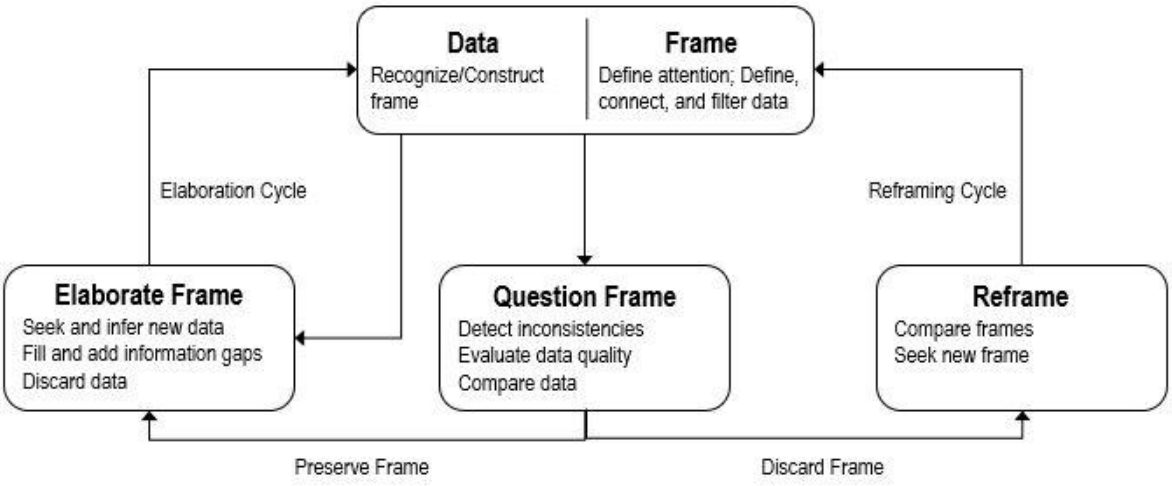


Figure 1. Four Functions of Sensemaking Cycle (Klein et al., 2007)

Shown in Figure 1, sensemaking develops within a frame (A) providing understanding of the situation at hand, to include gaps in understanding that can be addressed by seeking further information. When encountering a new situation, actors can infer frames using only a few data points referred to as "cues" (Weick, Sutcliffe, & Obstfeld, 2005) or "anchors" (Klein et al., 2007): "the initial one or two key data elements we experience sometime serve as anchors for creating an understanding. These anchors elicit the initial frame, and we use that frame to search

for more data elements" (p. 122). Incorporating social media in emergency dispatch requires understanding the repertoire of explanatory frameworks (i.e. frames) dispatchers use to interpret and seek information on social media, as well as the characteristics of social media data (i.e. cues) that facilitate analysis and information seeking (McMaster et al., 2012). To examine how dispatchers use frames in the context of emergency dispatch work, we therefore ask: *(RQ1) How do dispatchers analyze social media data within emergency dispatch workflows?*

The existing frame is elaborated (B) when new information is discovered that provides additional details about the situation. The elaboration loop in Figure 1 represents the process of seeking information to fill (or identify) information gaps and establish new relationships among newly-discovered and existing information characterizing the frame. Incorporating social media in emergency dispatch requires understanding a distributed process of elaboration in which call takers, analysts, and dispatchers seek, analyze, and integrate information from multiple data sources in ways that add to the collective understanding of an emergency. To examine how dispatchers discover new details and elaborate existing frames, we therefore ask: *(RQ2) How do dispatchers search social media data and integrate information from social media and 911 calls?*

Encountering inconsistent data calls into question (C) the existing frame, which can either be preserved and elaborated (to include discarding anomalous data), or reframed (D) by selecting a new frame. These encounters are critical insofar as they allow us to recognize errors and adjust our understanding of dynamic events. As dispatchers use information gathered from social media users and 911 callers to understand evolving emergency events, we ask: *(RQ3) How do dispatchers discover inconsistencies among information from social media and 911 calls?* Moreover, when information about an emergency (e.g. where, what, who) varies among social media posts and 911 calls, dispatchers must compare multiple, incomplete, and inconsistent reports across data sources and determine whether the information provides new details about a known emergency (i.e. elaboration), redundant information (i.e. preservation), or identifies a hitherto unreported emergency (i.e. reframing). Therefore, and lastly, to examine how dispatchers evaluate inconsistent information, we ask: *(RQ4) How do dispatchers determine if information from social media is supplemental, redundant, or novel?*

METHOD: EMERGENCY DISPATCH SIMULATIONS

This study reports findings from scenario-based emergency dispatch simulations conducted at a large, urban PSAP which processes approximately 3000 calls a day. The simulations were organized to provide the PSAP with procedural and technological requirements for incorporating social media in its emergency dispatch operations. Drawing on role play methods in interaction design, the simulations involved participating dispatchers performing the roles of call taker, dispatcher, and social media analyst in a constructed scenario (Medler & Magerko, 2010; Svanaes & Seland, 2004). Widely used in human-centered design, role playing allows researchers to observe plausible interactions among domain-experts and prospective end-users as they develop within hypothetical situations (Medler & Magerko, 2010), especially emergency situations which are difficult to directly observe and inappropriate for research activities (Valkonen & Liinasuo, 2010). The simulations involved six dispatchers performing in teams including a call taker, dispatcher (participants' professional duties in the PSAP), and social media analyst (new specialization under consideration by PSAP administrators), tasked with processing information from synthetic 911 caller and social media datasets using a simulated Computer-Aided Dispatch (CAD) system and analytic dashboard during two mock emergency scenarios.

During a prior workshop held at the PSAP in May 2018, researchers conducted activities with six dispatchers and 25 first responders (fire, medical, and police) to inform the design of two scenarios and associated synthetic social media and 911 call datasets. The workshop involved two activities. First, dispatchers and first responders composed "golden tweets," examples of social media posts that would support situational awareness needs of first responders (blinded for review). Discussed among the examples were golden tweets based on a mall shooting encountered by the PSAP the year prior. These motivated the creation of the *mall shooting dataset*, consisting of 20 emergency-related tweets, four mock 911 calls, and 1000 tweets collected for Charleston County on March 19th, 2018 from 4-6pm (as background noise). Second, sets of 50 weather-related tweets were provided to first responders to sort into piles of "actionable" and "non-actionable" information. The tweets were collected for Charleston County on April 15th, 2018 when the PSAP experienced high call volumes during a severe storm that caused flooding throughout the area. Using the sorted tweets and flood-related golden tweets, researchers created the *severe flooding dataset*, consisting of three emergency-related tweets, 1000 "noise" tweets collected on April 15th, and six mock 911 calls. Importantly, and inspired by our discussions with dispatchers and first responders, the mock tweets and 911 calls in both datasets provide incomplete information (e.g. "what" without "where" information), and therefore required dispatchers to compare and integrate information across these reports to support the situational awareness needs of first responders during each scenario.

Taking place during a follow-up workshop in August 2018, the simulations mimicked a live emergency environment by placing the participating dispatchers in the auxiliary dispatch room of the PSAP in which the call

taker, analyst, and dispatcher took up individual workstations and interacted asynchronously via text-based communication using the simulated CAD environment. The analyst was additionally provided with an analytic dashboard (Toepke, 2018), which included a map to examine geotagged tweets, tweet filtering and visualization using search terms, and word cloud displaying trending hashtags that could be individually selected to visualize associated tweets on the map and tweet list displays (Figure 2). A researcher with an audio recorder was present at each workstation where talk-aloud methods were employed to collect data from the call taker, analyst, and dispatcher as they processed calls or analyzed social media data during each scenario (Jaspers, Steen, Van Den Bos, & Geenen, 2004). The participant in the role of call taker communicated directly with the 911 caller (research confederate) and talked aloud with a researcher while entering information in the simulated CAD. Using activities of the sensemaking cycle- framing, elaboration, questioning, and reframing- as sensitizing concepts, researchers coded the transcribed audio recordings and textual data participants entered in the simulated CAD environment (Strauss, 1987). The researchers discussed and iteratively refined the coded data to address emergent aspects of the distributed sensemaking process, for instance, the use of cues and search heuristics among dispatchers when searching and filtering tweets during each scenario.

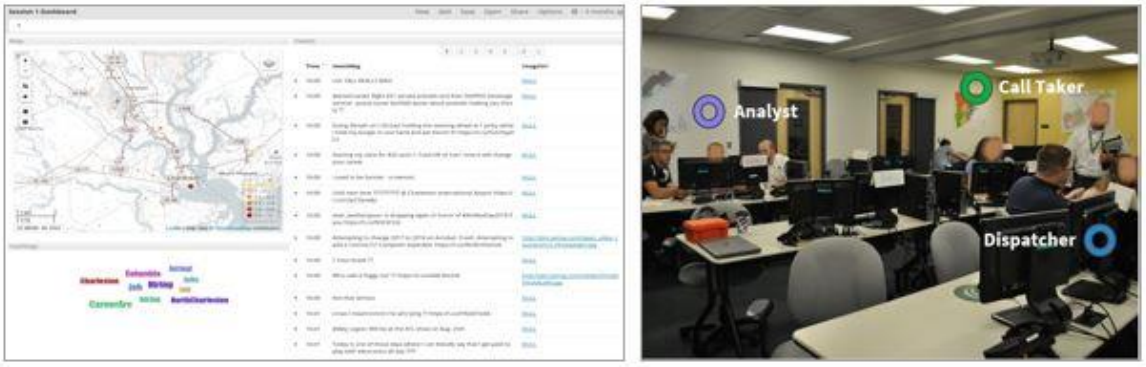


Figure 2. Social media analytics dashboard (left) used in simulations with mock CAD workstations (right)

ANALYSIS: MALL SHOOTING AND FLOODING SCENARIOS

For simulation scenario, a synopsis describes the actions performed by the call taker, dispatcher, and social media analyst, while annotations (*in italics)* associate these distributed activities with sensemaking activities of framing, elaborating, questioning, and reframing. The following discussion analyzes these sensemaking functions in detail by drawing on data collected as call takers, dispatchers, and, especially, social media analysts, explained aloud their actions during each scenario.

Scenario One: Mall Shooting

Scenario one begins when a 911 caller reports gunshots at Citadel Mall and, simultaneously, a dashboard alert identifies tweets describing a "shooting" (Table 1). The dispatch team next processes two additional 911 calls and multiple tweets reporting information on wounded victims, survivors sheltered in place throughout the mall, and the description and whereabouts of the suspect(s). Framing the Emergency using Primary Cues

Alerted that "shooting" had been tweeted, the analyst employs the word as a search term to identify three tweets reporting an emergency:

> #citadellMall #shooting Hiding in Journeys @NCPD 3 people here not injured @CCSO
>
> There are people running and screaming in the mall. Someone is shooting
>
> Shooting at citadel mall in Food Court. Shooter in just walked out

The call taker simultaneously answeres a 911 call describing "loud pops, like someone is shooting here...People were screaming and just running out of the store." Based on primary information cues (e.g. "Citadel Mall," "shooter," "loud pops"), the call taker and analyst recognize the incident type and location, and quickly enter calls 1-2 for an "active assailant" at Citadel Mall. By establishing the primary information necessary to dispatch a response (i.e. where and what), the call taker and analyst contribute to the emergency frame that will guide information seeking and integration among the call taker, analyst, and Dispatcher throughout the duration of the scenario.

Elaboration by Seeking Secondary Information

Next, the analyst searches for secondary information (e.g. weapons, who, when, why) that will support situational awareness among first responders now en route to the scene. Importantly, the emergency frame functions as a story, providing dispatchers with a likely order of events taking place at Citadel Mall, as well as a set of corresponding information requirements:

> For the initial response I want to know who the suspect is and what they look like and where they go… several people have reported that they've ran away so did they run out of the food court, did they run out of where? Did they get into a car? Everything about the suspect.
>
> Once the suspect issue has been dealt with by the police department, then… they can find out where the victims are… From there we would go into where people are sheltered in place. So suspect information first, then where the victims are, and then the sheltered in place. (Analyst, Scenario 1)

The emergency frame, in this case an active assailant incident at Citadel Mall, prioritizes situational awareness (i.e. secondary information) requirements to guide information seeking between the call taker and analyst as they search for new information and, ostensibly, dispatch information first responders need when they need it.

Table 1. Four phases of mall shooting scenario

Call Taker	Answers 911 call: "I'm outside Citadel Mall and there are loud pops like someone is shooting here. I just ran out of target and am driving away…" Enters an active assailant call (2) into CAD *[Framing: Active Assailant]*, and notes that there is no further information on potential suspects or injuries. *[Elaboration: Information gap]*
Analyst	Alerted to tweets describing a "shooting," searches and identifies three tweets and opens a call (1) for an active assailant in CAD *[Framing: Active Assailant]*: "several tweets reporting active shooter at the mall, one person reports near the food court and suspect is possible gone on arrival...one person reports 3 survivors sheltered in place in Journeys, negative injuries with this report." *[Elaboration: Survivors, Information gap]*
Dispatcher	Combines information entered by the call taker and analyst for dispatch (Call 1,2). Sends an alert tone for emergency units to respond to an active assailant incident in progress; begins to provide situational updates to first responders.
Analyst	Searches map; identifies geotagged tweet reporting injuries and enters additional call notes (1) in CAD: "multiple shot near food court and shooter is gone on arrival, no descriptions or specific locations of victims or suspect." *[Elaboration: Victims, Information gap]*
Dispatcher	"One party advising incident occurred near food court, suspect possibly gone on arrival, one party reporting three people sheltered in place at Journeys. Negative injuries reported at this time" (Call 1).
Call Taker	A second call comes in: "I'm in a back room in the store Belk. Someone is shooting and we are hiding here. There are three of us…" Enters a new call (3): "shots coming from inside the mall, poss. not in Belk; negative on any suspect information; negative on any known injuries; weapon unknown." *[Framing: Active Assailant; Elaboration: Information Gap]*
Analyst	Uses the search term "Belk" to discover reports of shots fired near the department store. Compares this information with call notes entered in CAD (3), and concludes the information is redundant. *[Questioning: Preserve frame (discard data)]*
Dispatcher	"Notification that there are still shots fired at this time, use caution. one caller advising they and two others are in Belk storage rooms sheltering in place… still no suspect info" (Call 3).
Call Taker	Another call (4): "I am outside Belk in the parking lot… I think there are two white guys with guns… Lots of people are running through the parking lot…" Makes further entries into CAD: "Parking lot outside of Belk; two white males, negative on clothing, unknown further; caller on the line, pending more suspect information." *[Elaboration: Suspects]*
Dispatcher	"Be advised, two white male suspects, armed, reported in the Belk parking lot" (Call 4). Requests further information from the call taker still speaking with the 911 caller: "...which parking lot of Belk?"

In the scenario, however, this never happens. The analyst adopts ineffective search terms and fails to discover most of the suspect information available in the tweet dataset during the scenario, notably:

> I'm locked in the women's room. There's a tall skinny white guy in blue jeans and a white tshirt.
>
> man with a gun just got into a red SUV and turned right on Orleans Rd
>
> shirtless man with assault rifle running to car outside the mall [picture of shirtless man next to a red SUV]

During both scenarios, analysts rely on search heuristics employed as 911 call takers, but which prove ineffective when adapted to filtering social media data (i.e. poor recall). Explaining that he has "seen a lot of people using the business name versus an address or road name," the analyst uses the department store name "Belk" referred to by an earlier 911 caller (Call 3). Relying on cues provided by 911 callers, analysts adopted similar heuristics, typically using the names of businesses or other geographic landmarks, to search generally for emergency-related information.

Consequently, analysts did not select search terms associated targeting specific, priority information. Instead, analysts provided information for dispatch as discovered, such as when the analyst provided information on survivors sheltered in place (Call 1) early in the response when suspect and victim information remained priorities. By using search terms explicitly provided by 911 callers or alerts provided by the analytic dashboard, the analyst reactively filtered social media data in ways that often proved ineffective at identifying and triaging priority information.

Elaboration by Identifying Gaps in Situational Awareness

Whenever entering new information into CAD, the call taker and analyst also described what information remained unknown: "negative injuries with this report" (Call 1), "unknown any injuries… no suspect information" (Call 2), "negative on any suspect information; negative on any known injuries; weapon unknown" (Call 3), "negative on clothing, unknown further" (Call 4). By identifying information gaps in CAD, the call taker and analyst support shared awareness among dispatchers and first responders during the response:

> When we got the additional tweet of multiple people shot, I went back to the original [call] notes I had [for Call 1] to report multiple people shot near the food court... the shooter is gone, and... that there are no descriptions or specific locations because some of these officers are going to ask for that. I know they are going to ask for that so I go ahead and tell them there is nothing more specific. (Analyst, Scenario 1)

Information gaps can be determined with respect to secondary information associated with the emergency frame: an active assailant at Citadel Mall. In scenario one, missing information included descriptions of weapons, the shooter, as well as potential victims and survivors sheltering in place. As previously described, however, the analysts' inflexible search heuristics precluded targeted information seeking to address information gaps articulated among the dispatchers.

Questioning and Discarding Redundant Information

In phase three of the scenario, the call taker enters a call (3) from a survivor sheltering in place in Belk, a department store in Citadel Mall. The analyst subsequently uses the search term "Belk" and identifies two tweets reading "loud pops near Belk in the mall. Sounds like a gun people running screaming" and "In Belk 🙏🙏🙏 #help #pray #charleston." The analyst compares this information to existing information entered in CAD and already dispatched to first responders:

> I searched for "Belk." I had one [tweet] pop up basically reporting what sounds like pops, or a gun going off… There is no additional information I can pull out of that. They already know there is a shooting at the mall near Belk, they already know people are running around and screaming. It's an active shooter incident. So, there is nothing additional I can pull from here to put into there… It's redundant information because everything that is here is already here [in CAD]. (Analyst, Scenario 1)

Although the tweets provide information related to the emergency, the analyst does not consider them relevant in the situation given the information already available and the evolving information requirements of the response. From a sensemaking standpoint, the phase illustrates the analyst questioning encountered information to gauge its quality with respect to information characterizing the existing frame. Concluding the former corroborates the frame without providing any new information for its elaboration, the analyst discards the data.

Scenario Two: Severe Flooding

Scenario two involves roadway flooding in different locations causing traffic hazards and the need for two water rescues. Table 2 provides a synopsis of the role play in three phases.

Discovering Inconsistencies among Information from Social Media and Emergency Callers

As in scenario one, the analyst did not readily discover information during each emergency, to include the discovery of inconsistencies among information that might lead to a reframing of awareness. In phase two, for

instance, the analyst enters a call for a traffic hazard on Harbor View Boulevard after searching "flooding" and discovering a tweet reporting flooding on Harbor View near Harris Teeter, a supermarket. What the analyst did not discover, however, was a tweet requesting a water rescue in the same location:

> So much water at Lake Francis near CVS. Rd. impassable. ONE PERSON STUCK IN CAR.

Lake Francis Drive intersects with Harbor View Boulevard immediately across from the shopping center parking lot in which both Harris Teeter and CVS, a pharmacy, are located. The analyst later discovers this tweet by accident when searching for "Pier One" after the store name was mentioned by a 911 caller reporting flooding eight miles away on Sam Rittenberg Boulevard- an unrelated incident. That the search results for "Pier *One*" returned a tweet reporting "*One* person stuck in a car" was purely serendipitous.

Table 2. Three phases of flooding scenario

Call Taker	Enters a call (1) into CAD when someone reports roadway flooding near the Dollar General on Camp Road. *[Framing: Traffic Hazard]*
Analyst	After checking tweets appearing on the map, then searching for "Dollar General" and "flooding," discovers tweet reporting a trapped person at the intersection of Dills Bluff and Camp Road. Determines this a distinct incident and enters a call (2) into CAD. *[Questioning: Inconsistent location; Reframing: Water Rescue]*
Dispatcher	Uses radio to dispatch a police unit to Camp Road (1), and then police, fire, and medical units to the Dills Bluff incident (2), noting: "units dispatched to both sides of the roadway to set up cones and Traffic and Transportation notified [of lane closures]."
Analyst	Also discovered when searching for "flooding," a tweet shows an image of flooding in the parking lot of Harris Teeter. Enters a call (3) into CAD. *[Framing: Traffic Hazard]*
Dispatcher	Dispatches a police unit to the Traffic Hazard near Harris Teeter (3) and asks the analyst to clarify the depth of the water in the tweeted picture: "what is a 4-5 drop zone?"
Call Taker	Another call arrives reporting more roadway flooding, this time near Pier One Imports on Sam Rittenberg Road. Enters another call (4) for a Traffic Hazard into CAD. [*Framing: Traffic Hazard*]
Analyst	Searching "Pier One," finds tweet reading "So much water at Lake Francis near CVS. Rd. impassable. ONE PERSON STUCK IN CAR." Determining that the CVS is in the same parking lot as the Harris Teeter, enters call notes (3) requesting a Water Rescue. *[Questioning: Inconsistent location; Reframing: Water Rescue]*
Dispatcher	Dispatches police to Traffic Hazard on Sam Rittenberg and uses CAD to ask the call taker if anyone is in the vehicles. "Caller did not advise," answers the Call taker. Dispatches units to a water rescue. In call notes (3) the dispatcher writes, "Copy, duplicating call for emergency Fire Rescue (EFR). Confirming information with police department on the scene."

As the example illustrates, the types of cues provided by 911 callers and entered into CAD by call takers condition analysts' discovery of emergency-related information. The previous example also illustrates the difficulty of discovering an emergency when no one calls 911; the initial call entered into CAD for a traffic hazard on Harbor View near Harris Teeter was entered earlier by the analyst after discovering a picture of the flooding on Twitter. That the analyst was not initially aware of the trapped person at the Harborview and Lake Francis intersection demonstrates, again, the difficulty of discovering unknown information about an unknown emergency.

Evaluating Inconsistencies among Information from Social Media and 911 Callers

Searching and filtering tweets, however, constitutes only the first step of integrating information from social media within 911 dispatch operations. Next analysts must compare newly-obtained information from social media displayed on the dashboard interface with existing, integrated information from 911 callers and social media displayed on CAD and shared among the call taker, dispatcher and analyst. At this stage inconsistencies appear when analysts cannot not determine if a discovered tweet(s) reports a new emergency not yet entered into CAD, new situational awareness information for a reported emergency, or redundant information about an already-reported emergency.

Consequently, the ability of analysts to evaluate inconsistencies among information displayed on the analytic dashboard, and between information displayed on the dashboard and CAD, becomes critical to effectively integrating information from social media and 911 callers for emergency dispatch. In phase one, for example, the analyst must determine if the trapped person at the intersection of Camp Road and Dills Bluff is related to the flooding earlier reported on Camp Road (near the Dollar General) by a 911 caller. Comparing the available

location information for each incident, the analyst determines them to be separate and therefore enters a new call into CAD for a water rescue, rather than adding additional information to the existing call for the traffic hazard.

To do this, however, the analyst uses primary information cues in the tweets, words that indicate the incident type and location of the emergency. When asked to consider a likely counterfactual, if the tweet had provided less detailed location information by omitting reference to Dills Bluff, the analyst describes *how* dispatchers evaluate and compare inconsistent information from multiple emergency reports:

> If this Dills Bluff thing wasn't here, and it just said lots of flooding on Camp Road, my car's flooded, I need a boat, [then] flooding on Camp Road is related to the Dollar General on Camp Road where there is a lot of flooding reported. I would add it to the same call then. However, because there is this specific location, I would probably create an entirely separate call. (Analyst, Scenario One)

Lacking the primary cue "Dills Bluff," and therefore presented with less exact location information, the analyst would infer that the traffic hazard and water rescue are colocated- both on Camp Road near Dollar General- and refer to the same roadway flooding. However, when presented with more detailed location information, the analyst concludes that the incidents are distinct, occurring at different locations along Camp Road.

The analyst is working with protocols for dispatching a response that require classifying an incident type- in this case a water rescue- and an exact location. If the cue "Dills Bluff" was omitted by the social media user or not presented to the analyst, only the Camp Road at Dollar General location would meet this latter criterion. From a sensemaking perspective, the example illustrates how the analyst relies on cues in data to either elaborate an existing frame (Camp Road at Dollar General) or construct a new frame using cues sufficient to classify an exact location (Camp Road at Dills Bluff). Importantly, the analyst relies on the bottom-up presentation of cues available in the data and, at the same time, the top-down recognition of sensemaking frames from the repertoire of locations available for dispatch in Charleston County.

Similarly, in phase three, when the analyst serendipitously discovers the tweet requesting a water rescue on Lake Francis Boulevard near CVS, he must still evaluate the tweet in comparison to inconsistent information entered into CAD for dispatch:

> So when I was looking for Pier One there weren't any geotagged tweets from the area [on the map] but it looks like there are additional ones that popped up [in the tweet search]. I found one tweet here, "water at Lake Francis near CVS, road impassable, one person stuck in the car." So now I would identify where this is, looking up Lake Francis, looking up some of the CVSs trying to figure out where this was. (Analyst, Scenario 2)

The report of someone trapped in their car near Lake Francis near CVS is not immediately intelligible as the same location as the traffic hazard on Harbor View near Harris Teeter. Both roadways are long thoroughfares, and there are multiple chain supermarkets and pharmacies with the same name in Charleston.

To compare this new information with that already entered into CAD, the analyst again looks to primary information cues in the tweet that allow dispatchers to classify information for emergency dispatch:

> I can use the CAD system to determine where is Harris Teeter, where is Lake Francis, and where is the CVS near Lake Francis.... I would just look for Lake Francis Drive and see if I could find a CVS near there, and then compare this report to the CAD to see if there was a call already entered and, if not, then I would go ahead and enter one for water rescue. So they wouldn't be getting much information but they would be getting enough for a location and a basic response for one person stuck in a car due to possible flooding. (Analyst, Scenario 2)

Using the names of roadways and stores as primary cues, the analyst uses mapping applications (typically integrated in CAD) to classify the location of the emergency and determine if an emergency has already been reported in the same location. In this situation, the analyst determines that the newly-reported water rescue, and the already-dispatched traffic hazard are colocated: "if this is the same location...the person stuck in the water in the car is due to the flooding, basically" (Analyst, Scenario 2).

DISCUSSION: INTEGRATING SOCIAL MEDIA VIA DISTRIBUTED SENSEMAKING

In contrast to prior studies which examine sensemaking among social media users posting and engaging social media content during a crisis (Mirbabaie & Zapatka, 2017; Stieglitz et al., 2018), or among officials gathering information from emergency callers (McMaster et al., 2012), this study examines how emergency dispatchers make sense of information gathered from social media and 911 calls to address evolving situational awareness needs during an emergency. Importantly, this study examines sensemaking as a distributed process performed among emergency dispatch teams including existing (call takers and dispatchers) and future (social media

analysts) specializations. Findings from the emergency dispatch simulations described in this study point to design requirements for social media analysis tools that can help analysts make sense of social media data created during an emergency, and protocols for coordinating analysts' sensemaking activities within emergency dispatch workflows capable of processing heterogeneous data to create actionable information.

Analyzing Information from Social Media and 911 Calls: Framing the Emergency

The simulations demonstrate how emergency dispatch teams make sense of information gathered from social media and 911 calls in sequences of sensemaking activities, or sensemaking workflows, which process and integrate information from heterogenous information sources to address the evolving situational awareness needs of first responders during an emergency. Drawing on Klein et al. (2006; 2007), this study observes four sensemaking activities constituting sensemaking workflows: framing, elaborating, questioning, and reframing. For each sensemaking activity, this study points to design implications for social media analysis tools that can help analysts make sense of social media data and protocols for coordinating analysts' sensemaking activities in workflows performed among emergency dispatch teams (Table 3).

Table 3. Design requirements supporting sensemaking by social media analysts

(Re)Framing	Cue Filtering	Identification and visualization of 6W cues in social media posts
	Domain Ontology	Incident determinant codes and information requirements (6Ws)
	COP	Situational awareness of calls and responding units
Elaborating	Assisted Search	6W-based classifiers to discover targeted information
	IS Protocols	SOPs to proactively address information gaps
Questioning	Alerts	Notifications to initiate sensemaking
	6W Visualizations	Visualizations contrasting 6W cues to reveal inconsistencies

The first activity, framing, sees dispatchers-turned-analysts make sense of social media data as they would 911 calls: associating data cues with a frame(s) explaining the situation. To analyze cues in social media data, analysts draw on the repertoire of frames commonly referred to as the "6Ws": Where, What, Weapons, Who, When, and Why (Kropczynski et al., 2018). The 6Ws represent a domain ontology organizing emergency dispatch work in which determinant codes representing classes of emergencies (i.e. what) are defined by attributes (i.e. where, weapons, who, when, why) with a set of possible values (e.g. street address in jurisdiction). Thus, analysts frame cues such as "loud pops," "shooting," and "Citadel Mall" with a determinant code indicating the class of emergency (e.g. 136E-1: Active Assailant) and a street address (e.g. 2070 Sam Rittenberg Blvd, Charleston, SC 29407). Thus, for analysts, effectively analyzing social media requires social media analysis tools that can filter information whose relevance is defined by the presence of cues enabling analysts to classify the attributes of an emergency (Kropczynski et al., 2018; Zade et al., 2018).

Framing practically involves entering a "call" in CAD whose primary information includes the "where" and "what" associated with an emergency, the minimum information required to dispatch emergency units. Highlighting the role of artifacts as frames (McMaster et al., 2012), and paired with the 6Ws domain ontology, calls displayed in CAD create a Common Operating Picture (COP) for a dispatch team, providing awareness of available information, information gaps, and the progress of emergency response operations. Together, cue filtering, the 6W domain ontology, and the function of CAD as a COP, enable analysts to create frames which, in turn, condition subsequent opportunities for distributed sensemaking activities of elaborating, questioning, and reframing.

Integrating Information from Social Media and 911 Callers: Elaborating the Emergency Frame

When a call is entered in CAD, the second phase of sensemaking proceeds as call takers and analysts seek to elaborate the existing frame by providing additional details about an emergency. As a frame, call information in CAD orients analysts' information seeking by articulating information requirements associated with gaps in "weapons," "who," "when," and "why" information prioritized according to the evolving needs of emergency responders. The simulations demonstrate how 911 calls entered in CAD provide analysts with resources for searching social media data and coordinating information seeking between call takers and analysts. However, the simulations also suggest analysts require assisted search features and information seeking protocols.

As a frame, a CAD call provides the dispatch team with a narrative of events happening during an emergency which analysts can, theoretically, use to search for priority information. In scenario one, for instance, the analyst knows that responders require immediate details about suspect(s) responsible for the mall shooting rather than survivors sheltering in place. However, while analysts use frames as stories to understand how information

requirements associated with chronological events will likely evolve during an emergency, the simulations suggest analysts must also use frames as scripts to coordinate proactive information seeking among dispatch teams. Such protocols would direct analysts to search social media data for priority information addressing the information gaps dispatchers describe in CAD whenever entering new information. Moreover, such protocols would encourage analysts to proactively search for missing information rather than reactively search for information when prompted by 911 callers.

Proactive information seeking, however, requires the ability to search and discover priority information. During both scenarios, analysts' search heuristics proved ineffective when filtering large social media datasets. To select search terms, analysts adapted techniques developed as call takers and searched for place names (e.g. "Camp Road," "Belk") mentioned by 911 callers. These queries resulted in poor recall of relevant information. Consequently, social media analysis tools in emergency dispatch will likely require assisted search capabilities leveraging, for instance, keyword-based classifiers that would allow an analyst working with a single cue, such as the department store name "Belk," to filter social media data associated with all toponyms in that geographic location. Similar approaches could be leveraged for each of the 6Ws, allowing, for example, an analyst using the cue "shot people" to filter social media data using keywords and n-grams associated with potential victims, i.e. "who." Future efforts to implement assisted search features in social media analytics dashboards can draw on the extensive research surrounding automated classification techniques for crisis-related information (Imran, Castillo, Diaz, & Vieweg, 2015), but must tailor these techniques to the domain ontology organizing information processing in emergency dispatch work (Kropczynski et al., 2018).

Evaluating Inconsistent Information: Questioning and Reframing the Emergency

When dispatchers discover inconsistencies, they must evaluate if the discovered information is novel, supplementary, or redundant in relation to information characterizing the existing frame. If determined novel, call takers or analysts can reframe the emergency by entering a new call in CAD or replace an existing call. Reframing produces a new frame for the dispatch team that, in turn, re-starts the distributed sensemaking cycle. For analysts, the emergency frame comes into question when noticing inconsistencies between newly-discovered information on social media and call information in CAD characterizing the existing frame. Analysts notice inconsistencies when comparing among information discovered on social media (e.g. do tweets refer to different locations?) and between information from social media and information in CAD (e.g. do tweets refer to the same locations as 911 callers?).

During the simulations, however, analysts recognize inconsistencies rarely and, in the case of the "Pier One" example, often inadvertently. Instead, analysts face a common problem in sensemaking: we don't know what we don't know. Consequently, analysts will likely require automated alerts to discover information about potential emergencies not yet reported by 911 callers. In the mall shooting scenario, the alert notifying the analyst that the word "shooting" was tweeted provides an example. Important questions regarding effective keywords, frequency thresholds, and other measures for triggering alerts extend beyond the scope of this study. Furthermore, analysts will likely require information visualizations that not only highlight relevant cues in social media data but draw attention to inconsistencies among (e.g. comparing all available location cues) and between (e.g. comparing location cues against incident cues) 6W information discovered on social media, and between 6W information discovered on social media and call information in CAD. The analytics dashboard employed during the simulations visualizes social media data in typical ways: plotted on a map, if geocoded, or filtered by search criteria in a social media stream. Understanding the domain ontology of emergency dispatch work, and how dispatchers use cues to frame social media data, can inform domain-specific visualizations that may help analysts detect inconsistencies challenging existing frames.

CONCLUSION

Our study must be considered in light of limitations attending simulated emergency dispatch work. Despite involving professional dispatchers in the design of the simulations, including the construction of the social media datasets, real-world conditions will, of course, vary significantly. Issues such as the need to verify information reported on social media were not fully addressed in this study although they remain an import consideration in emergency responders' uses of social media (Hiltz & Plotnick, 2016; Reuter, Ludwig, Kaufhold, & Spielhofer, 2016). Consequently, the design requirements offered here require further investigation and empirical evaluation. For instance, the design of alerts, as Boersma et al. (2016) observed, remains a difficult balance between recall and precision: too many undermine the value and effectiveness of user notifications while too few risk missing critical information. Moreover, the utility of alerts will necessarily depend on the information behaviors of social media users in a geographic community and use cases for emergency dispatch and response. Furthermore, additional research is required to design and evaluate visualizations that can support sensemaking activities such

as "questioning." While prior research can inform initial designs (Ntuen, Park, & Gwang-Myung, 2010; Stasko, Görg, & Liu, 2008), the domain-specific nature of information visualization will require iterative ideation and evaluation engaging dispatchers as domain experts and prospective end users.

Overall, the simulations conducted in this study suggest that social media analysts cannot adopt the reactive posture of call takers waiting on incoming 911 calls but must, instead, proactively seek and integrate missing information with information available from 911 callers. This proactive role will likely require effective filtering and automated alerts to notify the analyst of new and novel information, assisted search functions to increase the recall and precision of analysts' search queries, and information seeking protocols to address information gaps that evolve during an emergency response. Furthermore, analysts stand to benefit from custom visualizations that support top-down analysis by organizing and contrasting relevant information to assist sensemaking activities of framing, elaborating, questioning, and reframing.

REFERENCES

Boersma, K., Diks, D., Ferguson, J., & Wolbers, J. (2016). From Reactive to Proactive Use of Social Media in Emergency Response: A Critical Discussion of the Twitcident Project. In *Emergency and Disaster Management: Concepts, Methodologies, Tools, and Applications* (pp. 236–252). IGI Global. https://doi.org/10.4018/978-1-4666-9867-3.ch014

Furniss, D., & Blandford, A. (2006). Understanding emergency medical dispatch in terms of distributed cognition: a case study. *Ergonomics*, *49*(12–13), 1174–1203. https://doi.org/10.1080/00140130600612663

Grace, R., Kropczynski, J., & Tapia, A. (2018). Community coordination: Aligning social media use in community emergency management. In K. Boersma & B. Tomaszewski (Eds.), *Proceedings of the 15th ISCRAM Conference*. Rochester, NY.

Hiltz, S. R., & Plotnick, L. (2016). Barriers to Use of Social Media by Emergency Managers. *Journal of Homeland Security and Emergency Management*, *13*(2), 6–13. https://doi.org/10.1515/jhsem-2015-0068

Holland, L. (2018). Charleston County public can now connect with 911 via web - WCBD. Retrieved June 8, 2018, from http://www.counton2.com/news/local-news/charleston-county-public-can-now-connect-with-911-via-web/1128896475

Imran, M., Castillo, C., Diaz, F., & Vieweg, S. (2015). Processing Social Media Messages in Mass Emergency. *ACM Computing Surveys*, *47*(4), 1–38. https://doi.org/10.1145/2771588

Jaspers, M. W. M., Steen, T., Van Den Bos, C., & Geenen, M. (2004). The think aloud method: a guide to user interface design. *International Journal of Medical Informatics*, *73*, 781–795. https://doi.org/10.1016/j.ijmedinf.2004.08.003

Klein, G., Moon, B., & Hoffman, R. R. (2006). Making Sense of Sensemaking 2: A Macrocognitive Model. *IEEE Intelligent Systems*, *21*(5). Retrieved from www.computer.org/intelligent

Klein, G., Phillips, J., Rall, E., & Peluso, D. (2007). A Data-Frame Theory of Sensemaking. In R. Hoffman (Ed.), *Expertise Out of Context: Proceedings of the Sixth International Conference on Naturalistic Decision Making* (pp. 113–158). New York: Lawrence Erlbaum Associates.

Kropczynski, J., Grace, R., Coche, J., Obeysekare, E., Bénaben, F., Halse, S., … Tapia, A. (2018). Identifying Actionable Information on Social Media for Emergency Dispatch. In K. Stock & D. Bunker (Eds.), *Proceedings of ISCRAM Asia Pacific 2018* (pp. 1–11). Wellington, New Zealand.

Levine, E. S., & Tisch, J. S. (2014). Analytics in Action at the New York City Police Department's Counterterrorism Bureau. *Military Operations Research*, *19*(4), 5–14. https://doi.org/10.2307/24838523

McMaster, R., Baber, C., & Duffy, T. (2012). The role of artefacts in police emergency response sensemaking. In L. Rothkrantz & Z. Franco (Eds.), *Proceedings of the 9th International ISCRAM Conference* (pp. 1–10). Vancouver.

Medler, B., & Magerko, B. (2010). The implications of improvisational acting and role-playing on design methodologies. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10* (p. 483). New York, New York, USA: ACM Press. https://doi.org/10.1145/1753326.1753398

Mirbabaie, M., & Zapatka, E. (2017). Sensemaking in social media crisis communication: A case study on the Brussels Bombing in 2016. In *Proceedings of the 25th European Conference on Information Systems (ECIS)* (pp. 2169–2186). Guimarães, Portugal. Retrieved from https://aisel.aisnet.org/ecis2017_rp/138

Norri-Sederholm, T., Seppälä, J., Saranto, K., & Paakkonen, H. (2016). Information flow and situational awareness in emergency medical dispatch. *Int. J. Networking and Virtual Organisations*, *16*(1), 72–85. Retrieved from https://pdfs.semanticscholar.org/2cc6/200e278e41347836949ba1aba4defac1cbb7.pdf

Ntuen, C. A., Park, E. H., & Gwang-Myung, K. (2010). Designing an Information Visualization Tool for Sensemaking. *International Journal of Human-Computer Interaction*, *26*(2–3), 189–205. https://doi.org/10.1080/10447310903498825

Preusse, K. C., & Gipson, C. (2016). Dispatching Information in 911 Teams. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *60*(1), 117–121. https://doi.org/10.1177/1541931213601027

Reuter, C., Ludwig, T., Kaufhold, M.-A., & Spielhofer, T. (2016). Emergency services′ attitudes towards social media: A quantitative and qualitative survey across Europe. *International Journal of Human-Computer Studies*, *95*(C), 96–111. https://doi.org/10.1016/j.ijhcs.2016.03.005

Smith, C. (2018, March). The Controversial Crime-Fighting Program That Changed Big-City Policing Forever. *New York Magazine*. Retrieved from http://nymag.com/intelligencer/2018/03/the-crime-fighting-program-that-changed-new-york-forever.html

Stasko, J., Görg, C., & Liu, Z. (2008). Jigsaw: Supporting Investigative Analysis through Interactive Visualization. *Information Visualization*, *7*(2), 118–132. https://doi.org/10.1057/palgrave.ivs.9500180

Stieglitz, S., Mirbabaie, M., & Milde, M. (2018). Social Positions and Collective Sense-Making in Crisis Communication. *International Journal of Human–Computer Interaction*, *34*(4), 328–355. https://doi.org/10.1080/10447318.2018.1427830

Strauss, A. L. (1987). *Qualitative analysis for social scientists*. Cambridge University Press.

Svanaes, D., & Seland, G. (2004). Putting the users center stage. In *Proceedings of the 2004 conference on Human factors in computing systems - CHI '04* (pp. 479–486). New York, New York, USA: ACM Press. https://doi.org/10.1145/985692.985753

Toepke, S. L. (2018). Leveraging Elasticsearch and Botometer to Explore Volunteered Geographic Information. In K. Boersma & B. Tomaszewski (Eds.), *Proceedings of the 15th ISCRAM Conference* (pp. 663–676). Rochester, NY.

Valkonen, P., & Liinasuo, M. (2010). Role playing with fire fighters. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction Extending Boundaries - NordiCHI '10* (p. 805). New York, New York, USA: ACM Press. https://doi.org/10.1145/1868914.1869034

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2005). Organizing and the Process of Sensemaking. *Organization Science*, *16*(4), 409–421. https://doi.org/10.1287/orsc.1050.0133

Zade, H., Shah, K., Rangarajan, V., Kshirsagar, P., Imran, M., & Starbird, K. (2018). From Situational Awareness to Actionability. *Proceedings of the ACM on Human-Computer Interaction*, *2*(CSCW), 1–18. https://doi.org/10.1145/3274464

Counter Narratives in Social Media – An Empirical Study on Combat and Prevention of Terrorism

Amanda Langer[1] & Marc-André Kaufhold[1,2] & Elena Maria Runft[1] & Christian Reuter[2] & Margarita Grinko[1] & Volkmar Pipek[1]
Institute for Information Systems, University of Siegen[1]
Science and Technology for Peace and Security (PEASEC), TU Darmstadt[2]
amanda.langer@uni-siegen.de; marc.kaufhold@uni-siegen.de; reuter@peasec.tu-darmstadt.de; volkmar.pipek@uni-siegen.de

ABSTRACT

With the increase of terrorist attacks and spreading extremism worldwide, countermeasures advance as well. Often social media is used for recruitment and radicalization of susceptible target groups. Counter narratives are trying to disclose the illusion created by radical and extremist groups through a purposive and educational counter statement, and to initiate a rethinking in the affected individuals via thought-provoking impulses and advice. This exploratory study investigates counter narrative campaigns with regard to their fight and prevention against terrorism in social media. Posts with strong emotions and a personal reference to affected individuals achieved the highest impact and most reactions from the target group. Furthermore, our results illustrate that the impact of a counter narrative campaign cannot be measured solely according to the reaction rate to their postings and that further analysis steps are therefore necessary for the final evaluation of the campaigns.

Keywords

Counter Narratives, Online Campaign, Social Media, Terrorism, Radicalization.

1. INTRODUCTION

Information technology plays a major role in context of peace and security (Reuter, 2019). Social media are increasingly used by terror organizations such as the Islamic State (IS) to recruit new fighters, for internal communication and as a marketing platform to promote their own victories as well as their ideology (Neer and O'Toole, 2014). At the same time, they are also used by governments, organizations and private persons who are fighting against terrorism (Reuter et al., 2017b). During the past years, many different strategies to prevent terrorism and its extension in social media have been developed. Educational messages should display and refute the content spread by the IS in a corrected form, e.g. by using parodistic images.

"*Counter narratives*" is a method that has been getting more important in the last years to challenge extremist campaigns in social media (Briggs and Feve, 2013; Schmid, 2014). According to Tuck and Silverman (2016), a counter narrative opposes extremist narratives by offering counter arguments, revealing harmful and contradictory content, decreasing trustworthiness and emphasizing positive instead of negative notions. As extremist narratives, we understand all expressions by recognized terrorist groups that aim to justify their cause, radicalize their audience and even recruit followers, while terrorism is defined as "violence intended to force changes in political decisions, actions, or relationships where victims are targeted without regard for their degree or form of involvement in the conflict" (Turk, 2015). For an effective and successful application of counter narratives, the original narrative must be identified, decrypted and understood (ibid.). In comparison to counter narratives, however, other campaigns achieved more success during the last five years (Russell and Rafiq, 2016). Accordingly, our exploratory study intends to answer the research questions: **(RQ1) What are characteristics of social media posts that elicit the most reactions by the target group of counter narratives? (RQ2) What are potentials to improve the impact for counter narrative campaigns in social media?**

As a first part of the investigation, there will be a theoretical introduction to the method "counter narratives", as well as an overview of the related work in this context to illustrate the research gap (section 2). Afterwards, the

approach of the data collection, reduction and analysis will be exemplified (section 3). The next section presents the results in the form of identified categories, which merge the most popular social media posts in counter narrative campaigns (section 4). These results will be discussed and evaluated to conclusively answer the research questions, reveal the limitations of the study and give an outlook for further research (section 5).

2. BACKGROUND AND RELATED WORK

It has become evident in recent examples, such as the bombings in Brussels in March 2016, that social media users perform an important role providing information and support in scenarios where confusion is prevalent, and are sometimes faster than traditional media sources (Hughes et al., 2008; Mirbabaie and Zapatka, 2017). Although many citizens still do not feel concerned by conflicts and crises themselves (Reuter et al., 2017a), they consider it important to be warned, informed and instructed by authorities and sometimes rely on social media even more than other forms of information and communication technology (ICT) when it comes to crises (Shklovski et al., 2008). The use of ICT in the disaster context has been researched for more than a decade under the term of *crisis informatics* (Soden and Palen, 2018). In terrorism, social media occupy an important key role between the participating actors, as they operate both in the center of terror propaganda and counter-terror propaganda (Kaufhold and Reuter, 2019). Due to their diffuse and collaborative characteristics, social media can help distribute up-to-date information to broader audiences and yield fast reactions, and thus has the potential to act as an impulse for producing change in communication patterns as well as in society (Fischer et al., 2016; Reuter and Kaufhold, 2018). Therefore, we focus on social media as an important channel of the dissemination of terrorist propaganda and counter narratives.

2.1 Narratives as a Propaganda Tool

The term "*narrative*" originated from the social sciences and describes a story as a manifestation of social practice (Gubrium and Holstein, 2009). As a construction of stories (Halverson et al., 2011), the process of narration is dynamic and permanently changing the outcome (Gubrium and Holstein, 2009). Narratives are also used to convey moral messages and ideologies (Schmid, 2014). Consequently, we can gain insights in how cultural groups view the world framed by their emotions, opinions, attitudes and values: "Narratives are powerful resources for influencing target audiences" (Corman, 2011, p. 42). They provide an alternative form of reality whose basis is deeply rooted in culture and can be effectively used to interpret and shape local events, as well as to strategically promote specific types of individual operations. The impact of these narratives appears through the coherences and trustworthiness for the target audience (Goodall Jr, 2010), so that narratives have an importance for terrorism, extremism and radicalization. Narratives are used in terrorism to promote violence and in extremism to facilitate values which abandon human rights to recruit exposed persons for their own use (Russell and Rafiq, 2016). Extremist narratives are a composition of ideological, political, moral, religious and social narrations which are based on true or phantasmal stories (Briggs and Feve, 2013). As a consequence, black and white thinking emerges along with desensibilization, dehumanization, victimization and a call for activism and militancy. The IS uses the characteristics of narratives for its own propaganda and ideology. The mentioned topics can be divided into six categories: brutality, compassion, war, sacrifice, affiliation and utopianism (Winter, 2015). Within the last five years, the counter-movement of counter narratives evolved to refute their narratives.

2.2 Counter Narratives

Counter narratives reveal an alternative view of the problem and, ideally, lead to a new appreciation and a rethinking of the topic. The guideline from "The Counter-Narrative Handbook" defines counter narratives not only as a counterstatement to another narrative, but additionally as a "message that offers a positive alternative to extremist propaganda, or alternatively aims to deconstruct or delegitimize extremist narratives" (Tuck and Silverman, 2016). Their aim is to reveal hypocrisy and discrepancies in extremist propaganda and to undermine the trustworthiness of extremist groups. Counter narrative campaigns can spread from civil society, youth campaigns and non-governmental campaigns to strategic communication of the government. A campaign should follow a comprehensive goal and a number of specific, measurable and accessible sub-goals for self-control. Furthermore, the characteristics of the audience should be determined, e.g. based on stereotypes (Tuck and Silverman, 2016) and by examining their online behavior (Van Ginkel, 2015). The message should be carefully chosen and designed, and the actors' trustworthiness should be considered. To get a high range of influence for counter narrative posts in social media, it seems to be an effective method to frame the posts with keywords which are used likewise in posts by extremists (Van Ginkel, 2015). According to Tuck and Silverman (2016), inherently provocative campaigns promote reaction from the audience.

3. METHODOLOGY

To gain insights into the presented research issues, our method comprises the 1) identification of relevant social media campaigns, 2) data collection and reduction, as well as 3) data evaluation using grounded theory.

3.1 Identification of Campaigns

As a first step we identified popular (campaigns which have many followers on Twitter or likes on Facebook: *Average Mohamed, Abdullah-X, Think Again Turn Away, UK against Daesh*) or current (new campaigns which exist only since 2016: *FATE, Extremely Together*) campaigns to obtain a short overview of methods and impact in this area between April 2013 and March 2017. Our summary includes the description of the campaign, its strategy, an evaluation as well as a summarized conclusion based on our own observation (Table 1).

Campaign name, organizer and time frame	Strategy	Evaluation	Conclusion
#ThinkAgainTurnAway since March 2016: The Global Engagement Center U.S. State Department December 2013 until October 2016	• Daily posts on current events, links to related websites and similar campaigns, information about the IS, using known hashtags • (*#DeashLiesExposed*) • Directly addressing IS accounts • Target audience: Not defined, "one size fits all"	• >27.000 followers on Twitter • >11.000 likes on Facebook • (Negative) coverage in newspapers	• Highly criticized campaign • One-sided communication, conservative use of social media • Involvement in discussions with IS followers, articles from questionable sources • Government as unsuitable message deliverer
UK against Daesh UK government since July 2015	• Daily tweets on current events, links to related websites, spreading UK narratives, revealing progress in fighting the IS, using known hashtags *(#DefeatingDaesh*) • Creating surveys and Q&A sessions • Target audience: English-speaking public	>21.000 followers on Twitter	• Interaction with followers, attempts of a two-sided communication with the audience • Government as unsuitable message deliverer
Average Mohamed Non-profit organization by Mohamed A. Ahmed since July 2014	• Production of 1-minute cartoon videos on topics such as religion, politics and culture in order to refute extremist narratives with logical arguments • Main topics: Peace, democracy, anti-extremism • Target audience: Young American Muslims (8-16 y.o.)	• >80.000 website views in the first year • >160.000 total views on YouTube • Coverage on TV and in newspapers	• Popular campaign • Regularly maintained social media pages with further information • Engagement by Ahmed at schools and universities
Abdullah-X Anonymous (former extremist) August 2013 until the end of 2016	• Production of short cartoon videos on current events and topics youth are concerned with. Here, the former extremist is using his own experience and knowledge to reveal narratives • Target audience: Adolescent British Muslims (10-24 y.o.)	• >50.000 views on YouTube during 6-week test phase, >130.000 views in total • >1.000 followers on Twitter • Coverage on TV and in newspapers	• Campaign with great audience engagement in discussing and sharing the videos • High viewer retention rate
Extremely Together Kofi Annan Foundation since April 2016	• Team of 10 young people of different origins with anti-extremism experience, who present ideas, exchange experiences and provide suggestions for the collective fight against terrorism • Links to related websites, sharing information events, creating surveys • Target audience: Young Muslims with potential for recruitment	• >8.000 likes on Facebook • >1.000 followers on Twitter • >7.000 total views on YouTube	• Little popularity (so far), few reactions from audience • Online and offline presence • Interaction with audience, information events

Campaign name, organizer and time frame	Strategy	Evaluation	Conclusion
Families against Terrorism and Extremism (FATE) Independent consortium of 20 European *CVE* groups since March 2016	• Pan-European network of families and organizations • Daily postings on current events, information on the IS, emotional appeals, links to related websites and campaigns, early detection of radicalization process • Target audience: Young Muslims with potential for recruitment and their families	• Reaching >1,5 mil. users on Twitter and >2.500 on Facebook in 6-week test phase • Worldwide range of >600 mil. people • Coverage on TV and in newspapers	• Wide range, multilingualism, multimedia internet presence • Online and offline presence • Interaction with audience: Events, workshops, counseling

Table 1. List of campaigns, strategies and evaluation data (source: own research)

3.2 Data Collection and Reduction

Based on the derived overview of different campaigns, we started our data collection by reviewing all posts from the Facebook and Twitter timelines of the respective campaign accounts. In the case that YouTube videos are the basis of the campaign, the user comments supply the collected data. The period under review varied between the different campaigns based on the availability of data and the existence of the campaign at that time, but overall, the period under review was between April 2013 and March 2017, and includes a data set from n>10.000 findings (Table 2).

For an appropriate subsequent evaluation of the data, the quantity was reduced to 500 posts by limiting them to those with a response rate of at least 10 reactions. The campaigns' own retweets were not counted towards the other posts because they mainly represent reactions to other sites instead of the actual campaign, while we were interested in original content. *Abdullah-X* reached less than 50 posts after the reduction and was not considered in the following analysis. The campaign *FATE* had too few posts as well, which is why only the data from the Twitter account was considered. The amount of relevant posts by *UK against Daesh* was still too high, so the posts were reduced from 174 to 102 while sorting out redundant posts (Table 2). While the quantity of posts does not directly influence the results of a qualitative approach, it helps maintain the overview for a better comparison and categorization of posts.

Campaign	Medium	Period	Posts before reduction	Posts after reduction
The GEC	Facebook	2015-08-06 to 2016-05-26	906	89
UK against Daesh	Twitter	2016-05-08 to 2017-03-24	3,206	102
Average Mohamed	Facebook	2014-05-16 to 2017-03-23	329	27
	Twitter	2013-04-13 to 2017-03-23	341	99
	YouTube	End of 2014/2015 to 2017	99	
Abdullah-X	Twitter	2013-08-27 to 2016-11-09	1,033	7
	YouTube	Start of 2014 to 2017	41	41
Extremely Together	Facebook	2016-05-24 to 2017-03-24	374	33
	Twitter	2016-05-23 to 2017-03-24	708	40
FATE	Facebook	2016-11-19 to 2017-03-22	348	62
	Twitter	2016-08-24 to 2017-03-24	3,241	
Total			9,346	500

Table 2. Sources and periods of collected data

3.3 Data Evaluation using Grounded Theory

The qualitative data evaluation was carried out based on the grounded-theory method according to Glaser and Strauss (1967), which is characterized by a constant change between data collection and reflection, so that a continuous dialog takes place between pre-assumptions and the gathered data. For the encoding of the data, the procedure by Strauss and Corbin (1996) was used, a method where the data material is coded ad hoc – which means assigning it to a code which best describes the piece of data in relation to the whole data material – and the category scheme emerges gradually. Additionally, we used knowledge gained from our literature review to adjust our categories. Throughout the analysis process, the following core categories have been revealed: *Success,*

failures, linguistic differences, self-promotion, localization, visualization and *suggestions*. Subsequently, the posts inside the categories were evaluated for significant characteristics and qualities. The categories are characterized as follows:

- **Success**: differentiation between general achievements, and success in terms of failures of the IS. (a) negative expressions (e.g., "decrease", "lost", "problems"), messages on IS failures; (b) positive expressions (e.g., "successful", "help", "beautiful"), campaign success, establishment of countermeasures
- **Determent**: negatively connotated expressions and emotions (e.g. "hate", "grief", "lie"), emphasis on reality, revelation of deficiency, personal fates, emotional appeals / warnings
- **Self-promotion**: mentioning their own campaign and internal hashtags, interaction with the audience (call to action, questions, surveys), announcement of campaign events
- **Linguistic Differences**: analysis of the personal pronouns "we", "I", "they" as well as their declined forms
- **Localization**: naming specific cities / countries as well as expressions including the word "world" (e.g., "worldwide")
- **Visualization**: image and / or video included in a post
- **Suggestions**: specific instructions, prompts to act, imperatives (e.g., "must", "don't"), thought-provoking content, abstract expressions (e.g., "belief", "peace")

4. EMPIRICAL RESULTS

4.1 Success – Transportation of Success Stories Most Common Category

More than half of the posts can be assigned to the success category (61.4% of the postings). Within the category, they can differ between the following aspects: Failure of the IS, success of the particular campaign or country, and specific examples of the campaign's achievement. Joy, relief, pride or spitefulness can be a motivation for a reaction to this type of posts. Concrete and concise figures of failure can act as an eye catcher for a faster perception by the audience. In the following example, the loss of territory is addressed and because of that the campaign members classify it as a positive development in the fight against terrorism.

> *"UPDATE: #Daesh have lost 61% of territory in Iraq & 28% in #Syria […] #Defeating Daesh #ISIS #ISIL" (@UKagainstDaesh, 48♥55♲) (2016-12-26; the status of all quotations is 2017-03-24)*

Another facet in the success category consists of reporting on the positive results or advancement of the respective campaign or the country. These success stories' purpose is to show the effectiveness of the campaign, so that in an ideal case, the audience will be convinced of the respective campaign and support it. Another example clarifies the presentation of the campaign's own success through emotional posts and highlights the joint effort.

> *"#Beautiful moment as a father whose son joined #Daesh hugs @MoChirani. FATE brings people together to make us stronger than violent extremism" (@FATE_EN, 16♥10♲) (2016-11-16)*

Beside these success stories about the campaign, the coverage and support of similar activities falls into this category, emphasizing the common aim to prevent and fight extremism. Posts in this category got a lot of encouragement and an accordingly large number of reactions from the audience.

4.2 Determent – Strong Emotions and Facts Evoke More Reactions

This core category can be subdivided into aspects of clarification, emotional appeal and reporting on the consequences of extremism. Only in two campaigns (*The GEC* und *FATE*), more than half of the successful posts contained warnings (59,5%), whereas in the other campaigns, less than a quarter of posts are concerned (16,7%). An emotional appeal is particularly well suited for the use of counter narratives to touch a deeper level apart from the facts and to evoke a reaction from the audience. These reactions are ideally communicated by relatives and friends of radicalized fighters, in the form of sad or desperate stories. Emotional, personal stories do not have a specific target group; they touch a great number of people, thereby receiving a high encouragement, supporting the audience in feeling empathy and reacting accordingly to the posts.

"Extremely together's Ilwad Elman experienced the ongoing Syrian horrors first hand. He explains how seductive the lure of extremists in broken society can be and what must be done to resist them." (Extremely Together via Facebook, 24👍 34 ➥) (2016-05-26)

In contrast to emotional posts, there are fact-based reports on deficiencies in crisis areas. Whereas the official instances such as government accounts aim to inform the audience and give them the opportunity to participate in current events, other campaigns try to actively take action against the consequences.

4.3 Self-Promotion – Campaigns Enlarge their Range of Influence

Posts assigned to the self-promotion category aim to publish announcements, recruit new members or generate information from the audience. Most campaigns use more than two third of their posts for self-promotion. In total, self-promotion is mentioned in 61% of the posts.

"Thrilled to announce we'll be gathering in Brussels this month to launch our new #CVEtoolkit! Stay tuned […]" (@Xtremely2gether, 14♥ 11↻) (2017-03-17)

The low rate of self-promotion posts by government campaigns can be traced back to the missing individual character, like an introduction of new members etc. Via self-promotion, campaign leaders provide information about their own activities such as events, TV shows or interviews to the audience. Hereby, the campaigns convey activity, up-to-dateness and engagement outside the social platforms. Such posts are designed for interested users to become members of the campaign or to support it. Support can take place through a membership or through financial aid.

"[…] I need your help. We have $11 dollars in the bank need $3000 to reach 10,000 folks on Somali Independence Day on July 9th. We need funds to do this. Please do contribute and share with friends. […]" (Average Mohamed via Facebook, 25👍 24 ➥) (2016-06-27)

Surveys and direct questions have the purpose to identify the audience's opinion to get in contact more effectively. A major proportion of the self-promotion serves to recruit new members. Therefore, the project concept is shortly summarized in the posts, or a link to the campaign's website is included. Highlighting a positive impact of support by the audience should motivate to participate.

"Be part of #ExtremelyTogether. Share this tweet and reach 1.8 billion young people to counter extremism better" (@Xtremely2gether, 133♥ 254↻) (2016-09-29)

Besides the membership request, the audience is animated to interact with the posts of the campaign and thus identify with it more strongly, which can happen through a call to action, as well as through direct questions. Additionally, a lot of reactions from the audience imply a more distinct evaluation of the campaign.

4.4 Linguistic Differences – Explicit Distinction between Extremist and Counter Campaigns

The campaigns use linguistic differences between the extremists and their opponents by including different personal pronouns and direct forms of address. There is a differentiation between personal (I), connectedness (we), the others (they) and the direct address (you). The "I" form is used to express personal experiences, thoughts, opinions and feelings. The person in question talks directly to the audience or is directly quoted.

"They killed my parents. But I am still proud to call myself Belgian-Moroccan. "Not a dry eye at FATE right now." (@FATE_EN, 13♥ 7↻) (2016-11-15)

The sense of unity is intensified through emphasizing a common task and a common goal: By combining the forces, the goal can be easily achieved and obstacles can be overcome. "They" is used to include more people, but the speaker is clearly distancing themselves from them. This way, extremism opponents use "we" to draw a clear line between themselves and the terrorists who are referred to as "they".

"We are with you, we will stand together and take on the task of preventing radicalization in our young people. […]" (@FATE_EN, 10♥ 4↻) (2016-10-14)

The different perspectives of "I" and "we" are used to enhance the audience's identification with the campaigns, to not only address the counter terrorism movement, but also adolescents who are potential recruits. Government accounts do not apply this change of perspective, because there are no specific persons behind the accounts but employees of the government, who are representative of the whole country. The personal pronoun "we" is the most used personal pronoun inside campaigns and should convey a feeling of community and connectedness.

4.5 Localization – Used by all Campaigns to Strengthen the Benchmark

The posts in this category can be divided into cities or countries, crisis areas, and territorial limitlessness. All campaigns contain posts with location details (46.6% on average). The localization of events or incidents in crisis areas provides more detailed information about the topic of terrorism and counter narratives to the audience: Where is help needed? What countermeasures are taken in my city? Which areas have been taken by the IS?

"Follow us today as we get the #ExtremelyTogetherRoadshow rolling making counter narratives in Portsmouth" (@Xtremely2gether, 7♥ 10↻) (2017-02-07)

In contrast to this, phrases such as "worldwide" are showing the territorial limitlessness of posts. More than half of the most popular posts from government campaigns contain details on localization, for *UK against Daesh* this can be attributed to mentioning their own country in the campaign name. Therefore, it is surprising that a transnationally active campaign such as *FATE* contains the least location specifications.

4.6 Visualization – Pictures and Videos Serve as an Eye Catcher

The visualization of facts is useful in the international context to overcome linguistic barriers. Pictures (53.4%) and videos (26,6%) support the message, so that it is not surprising that all campaigns using visual content and visually supported posts show a higher response rate than purely textual posts.

Figure 1: Characteristic Pictures and Videos

We can differentiate between automatically displayed images, e.g., by linked articles, or consciously placed pictures or video screenshots. An article linked in a post can be viewed as an additional animation for the audience, yet the campaigns have no influence on displayed pictures. The majority of the campaigns' visual material can be attributed to this preview function. For graphics uploaded by the campaign leaders themselves, the campaigns apply different strategies for the use of visual material. For one part, it is used to introduce the team to create a personal bond with the audience; other motives can be to establish credibility or to visually support the post content. The other part is the promotion of self-produced video material, which are also published on platforms such as YouTube.

4.7 Suggestions – Too Few Thought-Provoking Impulses in the Campaigns

We found suggestions for preventing and fighting radicalization, which can be subdivided into one or more categories such as thought-provoking impulses, suggestions for countermeasures, and appeals. Accordingly, it is surprising that in almost all campaigns, posts with suggestions account for roughly a quarter of the most popular posts (26%). While in *Extremely Together*, at least a bit more than half of the most popular posts can be assigned to the category of suggestions, *UK against Daesh* offers no thought-provoking impulses at all. An important thought-provoking impulse, especially for family members and friends of individuals who have the potential to be recruited, is the sensibilization for the recruiting and extremism issue.

"Has your #friend's/#daughter's/#son's/#sibling's #behaviour changed quite a lot? Don't ignore the signs! #radicalisation #findFATE" (@FATE_EN, 10♥ 9↻) (2016-11-22)

Such thought-provoking impulses can be internalized by the audience, but in the fight against extremism, not only the right attitude is crucial, but also the following actions. Therefore, all campaigns provide concrete suggestions how one can actively operate against extremism. Because most of the evaluated counter narrative campaigns concentrate on social media, as a logical consequence, one suggestion which all campaigns give is: Fight extremist ideas online! The campaigns' prompts mostly contain no specific instructions, but are expressed in a rather abstract way:

"If you see something – say something #OYWOttawa #xtremely2gether" (@Xtremely2gether, 19♥ 24↻) (2016-09-29)

5. DISCUSSION AND CONCLUSION

Since 2012, a variety of counter narrative campaigns and projects with the aim to prevent and fight extremism and terrorism have emerged in social media (Tuck and Silverman, 2016). Our paper summarized many of them in Table 1 as a groundwork for our study. In most cases, the decisive criteria of success are set by the campaigns' founders or leaders in relation to their own aims, so that the result will be assessed in accordance with those aims. Their prevention work focusses on the target groups of teenagers who are in danger of being recruited in order to prevent their radicalization, since extremist narratives have the most effect on this target group.

With regard to our first research question (**RQ1: What are characteristics of social media posts that create the most reactions by the target group of counter narratives?**), we found out that success stories, determent, self-promotion, linguistic differences, localizations, visualization and suggestions are characteristics of social media posts that promoted most reactions by the target group. The audience prefers posts in the form of reactions connected to a feeling of *success*, since more than 61% of the posts can be assigned to this category. Similarly, personal fates as well as stories of former extremists, victims' family members or campaign leaders are popular (*determent*). The purpose of strong emotions is one of the characteristics responsible for the success extremist campaigns gain with their narratives (Winter, 2015), so it is understandable that those aspects produce the highest effect in a counter campaign as well. While emotional appeals evoke the respective emotion, surveys are more suitable for obtaining required information from the audience. An integrated call to action gives interested persons the opportunity to play an active role (*self-promotion*). For all these fields, photographic material (53% of the posts) and video footage (27%) have an effect as an eye catcher and get a high reaction rate from the audience (*visualization*). The results clearly show that while there is a low number of hints and advices (26%, *suggestions*), the percentage of self-promotion of the campaigns with the attempt to mobilize the audience is much higher (61%).

This leads to the second research question **(RQ2: What are potentials to improve the impact for counter narrative campaigns in social media?**). Firstly, counter narrative campaigns should be integrated with other counterterrorism efforts. One issue is the low degree of popularity in most campaigns, so that the campaign is hardly perceived. Research indicates that reactions and interactions of the audience are much higher for other strategies, such as the approach to fight extremism with humor (Al-Rawi, 2016; Reuter et al., 2017b) in satire-based campaigns such as #TrollingDay. Furthermore, so-called *alternative narratives* are intended to paint a fact-based picture of and give suggestions related to topics discussed in terrorist propaganda (Starbird, 2017). Secondly, while social media are an effective tool to support emergency response and crisis management, this is also true for other ICT (Fischer et al., 2016; Hughes et al., 2008; Kaufhold et al., 2018b; Mirbabaie and Zapatka, 2017; Shklovski et al., 2008; Soden and Palen, 2018). Therefore, an increased cooperation with established formats could increase the coverage and gain more attention for the campaigns' work in general in such a way that the dynamics of countermeasures are not limited to social media, but that the more intensive and convincing interacting with potential target groups can be intensified in real world activities as well. Thirdly, narratives and counter narratives also occur during natural hazards, as the case of FEMA's fail and redemption during the hurricanes Sandy and Katarina demonstrate (Drennan, 2018). Thus, it might be important to integrate the concepts of narratives and counter narratives into authorities' guidelines, policies and strategies (Kaufhold et al., 2018a) in order to identify and refute harmful or wrong narratives.

Our exploratory study is subject to limitations. A large amount of data had to be excluded from further analysis due to the low reaction rate of the audience. However, it could be worthwhile examining and contrasting the characteristics of posts with low reaction rates by applying a quantitative approach on a larger and more representative data sample. Since most counter narrative campaigns address a very specific target group and do not achieve high reaction rates on their posts, it should therefore be examined whether these posts still can provide starting points to effectively place counter narrative campaigns in social media. Especially from a communicative and linguistic point of view, the posts should be further analyzed to establish a valid distinction between terrorist propaganda and alternative narrations. With regard to ICT, we assume that event detection techniques and machine learning classifiers (Imran et al., 2015) could assist in the identification of extremist content and narratives, thereby establishing starting points for counter narrative actions. Furthermore, user interfaces might support the creation of high-impact social media postings via contentual recommendations based on criteria such as these discussed within our analytical categories.

ACKNOWLEDGEMENTS

This work was supported by the German Federal Ministry for Education and Research (BMBF) in the project KontiKat (13N14351).

REFERENCES

Al-Rawi, Ahmed (2016). Anti-ISIS Humor: Cultural Resistance of Radical Ideology. *Politics, Religion & Ideology*, vol. 17, no. 1, pp. 52–68.

Briggs, Rachel; and Sebastien Feve (2013). *Review of Programs to Counter Narratives of Violent Extremism: What Works and What are the Implications for Government?*. London, UK.

Corman, Steven R. (2011). Understanding the role of narrative in extremist strategic communication. In L. Fenstermacher; T. Leventhal; and S. Canna (eds.): *Countering violent extremism: Scientific Methods & Strategies*. Dayton: Air Force Research Laboratory, pp. 36–43.

Drennan, Lex (2018). FEMA's fall and redemption - applied narrative analysis. *Disaster Prevention and Management*, vol. 27, no. 4, pp. 393–406.

Fischer, Diana; Oliver Posegga; and Kai Fischbach (2016). Communication Barriers in Crisis Management: A Literature Review. In *European Conference on Information Systems (ECIS)*. Istanbul, Turkey: AISeL, pp. 1–18.

Glaser, Barney G.; and Anselm L. Strauss (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*. New York: Aldine de Gruyter.

Goodall Jr, Harold L. (2010). *Counter-Narrative: How Progressive Academics Can Challenge Extremists and Promote Social Justice*. London, UK: Routledge.

Gubrium, Jaber F.; and James A. Holstein (2009). *Analyzing narrative reality*. New York, NY: Sage Publications, Inc.

Halverson, Jeffry R.; H. L. Goodall Jr; and Steven R. Corman (2011). *Master narratives of Islamist extremism*. Basingstoke, UK: Palgrave Macmillan.

Hughes, Amanda Lee; Leysia Palen; Jeannette Sutton; Sophia B. Liu; and Sarah Vieweg (2008). "Site-Seeing" in Disaster: An Examination of On-Line Social Convergence. In *Proceedings of the 5th International ISCRAM Conference*. Brussels, Belgium: ISCRAM, pp. 1–10.

Imran, Muhammad; Carlos Castillo; Fernando Diaz; and Sarah Vieweg (2015). *A Processing Social Media Messages in Mass Emergency: A Survey*. *ACM Computing Surveys*, Vol. 47. New York, NY: ACM.

Kaufhold, Marc-André; Alexis Gizikis; Christian Reuter; Matthias Habdank; and Margarita Grinko (2018a). Avoiding chaotic use of social media before, during, and after emergencies: Design and evaluation of citizens' guidelines. *Journal of Contingencies and Crisis Management*, pp. 1–16.

Kaufhold, Marc-André; and Christian Reuter (2019). Cultural Violence and Peace in Social Media. In C. Reuter (ed.): *Information Technology for Peace and Security - IT-Applications and Infrastructures in Conflicts, Crises, War, and Peace*. Wiesbaden, Germany: Springer Vieweg.

Kaufhold, Marc-André; Nicola Rupp; Christian Reuter; Christoph Amelunxen; and Massimo Cristaldi (2018b). 112.social: Design and Evaluation of a Mobile Crisis App for Bidirectional Communication between Emergency Services and Citizens. In *European Conference on Information Systems (ECIS)*. Portsmouth, UK: AISeL.

Mirbabaie, Milad; and Elisa Zapatka (2017). Sensemaking in Social Media Crisis Communication – a Case Study on the Brussels Bombings in 2016. In *Twenty-Fifth European Conference on Information Systems (ECIS)*. Guimarães, Portugal, pp. 2170–2186.

Neer, Thomas; and Mary Ellen O'Toole (2014). The Violence of the Islamic State of Syria (ISIS): A Behavioral Perspective. *Violence and Gender*, vol. 1, no. 4, pp. 145–156.

Reuter, Christian (2019). *Information Technology for Peace and Security - IT-Applications and Infrastructures in Conflicts, Crises, War, and Peace*. Wiesbaden, Germany: Springer Vieweg.

Reuter, Christian; and Marc-André Kaufhold (2018). Fifteen Years of Social Media in Emergencies: A Retrospective Review and Future Directions for Crisis Informatics. *Journal of Contingencies and Crisis Management (JCCM)*, vol. 26, no. 1, pp. 41–57.

Reuter, Christian; Marc-André Kaufhold; Inken Leopold; and Hannah Knipp (2017a). Katwarn, NINA, or FEMA? Multi-Method Study on Distribution, Use and Public Views on Crisis Apps. In *European Conference on Information Systems (ECIS)*. Guimarães, Portugal: AISeL, pp. 2187–2201.

Reuter, Christian; Katja Pätsch; and Elena Runft (2017b). IT for Peace? Fighting Against Terrorism in Social

Media – An Explorative Twitter Study. *I-Com: Journal of Interactive Media*, vol. 16, no. 2.

Russell, Jonathan; and Haras Rafiq (2016). *Countering Islamist Extremist Narratives: A Strategic Briefing*. London, UK.

Schmid, Alex P. (2014). *Al-Qaeda's "Single Narrative" and Attempts to Develop Counter-Narratives: The State of Knowledge*. The Hague, Netherlands.

Shklovski, Irina; Leysia Palen; and Jeannette Sutton (2008). Finding community through information and communication technology in disaster response. In *Proceedings of the 2008 ACM conference on Computer Supported Cooperative Work (CSCW '08)*. New York, NY: ACM, pp. 127–136.

Soden, Robert; and Leysia Palen (2018). Informating Crisis: Expanding Critical Perspectives in Crisis Informatics. In *Proceedings of the ACM on Human-Computer Interaction*. New York, NY: ACM.

Starbird, Kate (2017). Examining the Alternative Media Ecosystem Through the Production of Alternative Narratives of Mass Shooting Events on Twitter. In *Proceedings of the Eleventh International Conference on Web and Social Media*. Palo Alto, CA: AAAI Press, pp. 230–239.

Strauss, Anselm; and Juliet Corbin (1996). *Grounded Theory: Grundlagen Qualitativer Sozialforschung*. Weinheim, Germany: Beltz.

Tuck, Henry; and Tanya Silverman (2016). *The Counter-Narrative Handbook*. London, UK.

Turk, Austin T. (2015). Terrorism and Counterterrorism. In E. Goode (ed.): *The Handbook of Deviance*. Hoboken, NJ: John Wiley & Sons, Inc, pp. 537–548.

Van Ginkel, Bibi (2015). *Responding to Cyber Jihad: Towards an Effective Counter Narrative*. The Hague, Netherlands.

Winter, Charlie (2015). *The Virtual "Caliphate": Understanding Islamic State's Propaganda Strategy*. London, UK.

Understanding Patterns and Mood Changes through Tweets about Disasters

Liuqing Li and Edward A. Fox
Department of Computer Science, Virginia Tech
Blacksburg, VA 24061, USA
[liuqing, fox]@vt.edu

ABSTRACT

We analyzed a sample of large tweet collections gathered since 2011, to expand understanding about tweeting patterns and emotional responses of different types of tweeters regarding disasters. We selected three examples for each of four disaster types: *school shooting*, *bombing*, *earthquake*, and *hurricane*. For each collection, we deployed our novel model TwiRole for user classification, and an existing deep learning model for mood detection. We found differences in the daily tweet count patterns, between the different types of events. Likewise, there were different average scores and patterns of moods (fear, sadness, surprise), both between types of events, and between events of the same type. Further, regarding surprise and fear, there were differences among roles of tweeters. These results suggest the value of further exploration as well as hypothesis testing with our hundreds of event and trend related tweet collections, considering indications in those that reflect emotional responses to disasters.

Keywords

Disaster, Pattern, User Classification, Mood Detection, Twitter

INTRODUCTION

Disasters can appear in any area of the world, and include both natural disasters like earthquakes, hurricanes, floods, and forest fires, as well as man-made disasters such as shootings, bombings, and train crashes. Different types of disasters have distinct patterns. For example, natural disasters have dramatic effects and can bring huge loss, while man-made disasters often proceed rapidly, with long-lasting impact. Further, natural disasters have particular spatial distribution patterns (Shen et al. 2018). Since Twitter users tend to tweet about the latest developments, and convey emotional feelings in a time of disaster, the patterns found in large tweet collections can reflect public concern about disasters, and help researchers dive deeper into understanding them.

Twitter users express different moods during disasters. For instance, some users may be frightened by the aftershocks during an earthquake, some are angered by a bombing disaster, and others verbalize their sadness for the victims in a school shooting event. Their changes in mood, synchronized with the unfolding of disasters, are interesting to explore. In addition, Twitter users assuming different roles (e.g., brand/organization, female, male) behave differently. For example, preliminary work has shown that male users prefer technology and sports (Bamman et al. 2014), female users are more emotional (Rao et al. 2010), and brand users act as broadcasters by spreading information or delivering messages. The gender value can be set by a user or predicted by Twitter on the profile page, but it is unreadable to others and does not include the brand class. Since moods might vary with time among different roles of users, analyzing such changes will be helpful both academically and practically. Social scientists can conduct user-related research, while disaster assistance can help victims recover, through targeted services.

In this paper, we report on a comprehensive analysis of 12 large tweet collections, to understand tweeting patterns and mood changes of different types of tweeters about disasters. We prepared three tweet collections for each of four disaster types: *school shooting*, *bombing*, *earthquake*, and *hurricane*. We developed TwiRole, a novel hybrid model to identify role-related users, and reused an existing recurrent neural network (RNN) model to detect the moods expressed in tweets. Considering both user roles and mood scores, we studied patterns and mood changes at

both the event and role level. To help investigate patterns and changes associated with disasters, we developed the following research questions: 1) Is there any tweeting pattern behind disasters of each type? Are these patterns similar between different types? 2) How do tweeters demonstrating different roles relate to these disasters? 3) What is the major mood? Are there exceptions? 4) How does mood change along with the daily tweet count pattern in each disaster? 5) Is there any difference in mood change among roles of tweeters?

The findings of our study indicate that different types of disasters lead to different daily tweet count patterns. Regarding user participation, brand users played an essential role in tweeting, while male users were more active than female users. There were different average scores and patterns of moods (fear, sadness, surprise), both between types of events, and between events of the same type. Fear is the major feeling in most disasters, while sadness is dominant in two of the school shootings analyzed. Mood delays exist in most disasters, where sadness is more time-sensitive. Regarding surprise and fear, mood variation appears among users with different roles.

We next present related work, and then describe our methodology for data selection, user classification, and mood detection. After that, findings, followed by evaluation and discussion, are presented in detail. Our conclusions are drawn in the final section.

RELATED WORK

User Classification on Twitter

Several researchers have worked on Twitter user classification according to role. Multiple features have been considered and extracted for gender classification. (Liu and Ruths 2013) investigated the relationship between first name and gender, and took the first name as an important feature for gender prediction. Some researchers have found that female and male users may apply templates in different colors (Alowibdi et al. 2013a; Alowibdi et al. 2013b; Fortmann-Roe 2013), and so utilized color-based features in gender inference. Information in user profiles, especially the descriptions of users, may also contain gender-based terms or phrases (e.g., man, woman, actor, mother) that are good indicators (Daas et al. 2016; Vicente et al. 2015). Besides these features, a user's network and behavior (Ciot et al. 2013; Lasorsa 2012; Nilizadeh et al. 2016), external sources (e.g., personal website, Facebook) (Burger et al. 2011), tweets (Artwick 2014; Bamman et al. 2014; Li et al. 2014; Pennacchiotti and Popescu 2011a; Geng et al. 2017; Rao et al. 2010), and profile images (Levi and Hassner 2015; Wang et al. 2016), have been advocated for gender classification.

In addition to the traditional bi-classification, (Purohit and Chan 2017) categorized Twitter users into organization, organization-affiliated, and non-affiliated, while (Pennacchiotti and Popescu 2011b) classified Twitter users as either Democrat or Republican. However, there are methodological concerns regarding the evaluation of such studies, because most approaches were evaluated on self-labeled datasets, and performance is still unclear on other datasets. We developed TwiRole, that applies multiple simple features as well as some novel features for 3-way (i.e., brand, female, and male) classification of tweeters. After training and testing TwiRole on an open third-party dataset, we also evaluated its performance on our disaster collections.

Sentiment / Emotion Classification on Twitter

There has been growing interest in sentiment and emotion classification of tweets. (Schulz et al. 2013) took unigram, part-of-speech, syntactic, and sentiment information as features for sentiment analysis. (Nagy and Stamberger 2012) detected tweet sentiments during crisis situations by using sentiment words, emoticons, and a list of out-of-vocabulary words. (Caragea et al. 2014) performed sentiment classification of tweets during Hurricane Sandy, and visualized these sentiments on a geographical map. Many studies have been published on basic sentiment analysis (i.e., positive, negative, and neutral) by applying traditional machine learning techniques (e.g., Naive Bayes, support vector machine, logistic regression). (Wendland et al. 2018) applied an appraisal system to account for the interpersonal assessment of speakers and associated attitudes, which evaluated the sentiments of tweets from several aspects such as appreciation, affect, and judgment. A recent study reported in (Colneriĉ and Demsar 2018) improved the classification performance using RNN deep learning. Instead of detecting the three basic sentiments, their model predicted tweet emotions, which can better describe the feelings of tweeters. The default task is for predicting Ekman's six basic emotions (Ekman 1992), while the other two aim to identify the eight moods developed by Plutchik (Plutchik 1990), and the six mood states from the profile of Mood States (POMS) (Norcross et al. 1984). In our study, we deployed the innovative RNN deep learning model to predict the moods of users through tweets.

Empirical Study in Disasters

Regarding social media studies in crises, some researchers are focusing on single disasters, such as the 2011 Egyptian uprising (Kavanaugh et al. 2013), 2011 Japan Earthquake (Wilensky 2014), 2012 Hurricane Sandy (Caragea et al. 2014; Neppalli et al. 2016), 2013 River Elbe Flood (Herfort et al. 2014), 2016 Ghana Election (Moreno et al. 2017), or 2016 Berlin Terrorist Attack (Fischer et al. 2018). (Yang et al. 2013) designed PhaseVis, a multi-view integrated visualization tool, and applied it to Hurricane Isaac. (Lee et al. 2012) built a prototype of a digital library to detect and visualize water main breaks in disaster and other areas. (Alam et al. 2018) analyzed the multimedia content from three hurricane collections. Novel theories, models, and techniques have been developed and applied, and researchers can make further discoveries or tell exciting stories about these disasters. However, the generality of these approaches is not clear. It is uncertain how well they can work on other disasters. To the best of our knowledge, this is the first investigation of groups of disasters, carried out in a systematic empirical study, combined with both user classification and mood detection.

METHODOLOGY

Figure 1 shows the data flow of our analysis across disaster types. First, we created three tweet collections for each of four types of disasters. Second, we identified users from the cleaned tweets after preprocessing. Third, we designed and implemented TwiRole [1], a hybrid model for user classification on Twitter, which detects brand-, female-, and male-related users. Then, we applied a pre-trained RNN model to predict the moods of tweets. Finally, we carried out a comprehensive analysis of disaster patterns and mood changes, considering both user roles and mood scores.

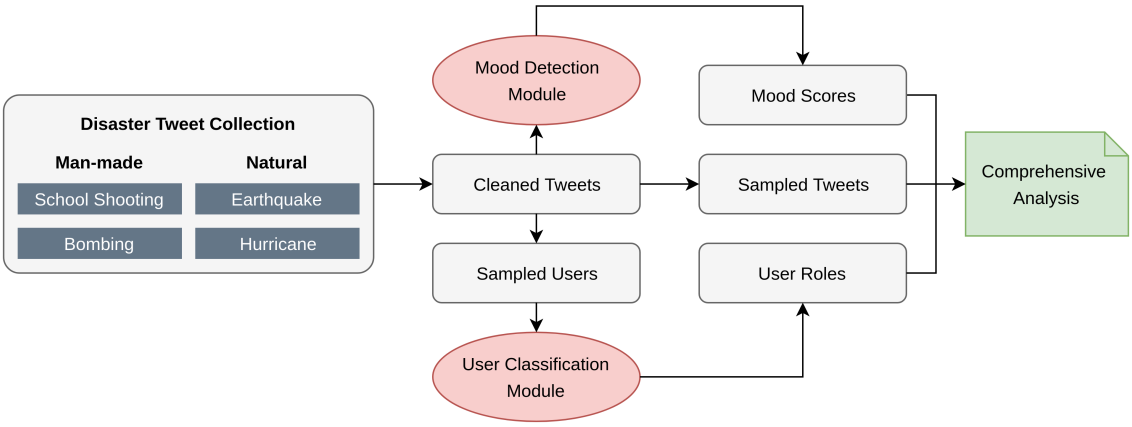


Figure 1. A data flow diagram: selection, classification, and analysis

Data Selection and Cleaning

Though we already had hundreds of tweet collections dating from 2012, we applied GetOldTweets3 (Mottl 2018) to create a dozen larger, more complete, tweet collections with four different types of disasters (i.e., school shooting, bombing, earthquake, and hurricane), three event collections per type. Each search query includes a disaster name and bound dates. The time range of each collection covers up to about one month after the corresponding disaster. For example, regarding hurricanes, we found the date they first formed, according to Wikipedia, and obtained tweets for four weeks starting on that date. Later, retweets (RTs) and non-English tweets were filtered out during cleaning to avoid muddling of results and to meet the input requirements of the mood detection module, respectively. Table 1 shows the details of our collections.

Role-related User Classification

We designed and implemented TwiRole to classify users by role. This hybrid classifier has a basic feature (BF) multi-classifier, an advanced feature (AF) multi-classifier, a convolutional neural network (CNN) model, and a final multi-classifier, as shown in Figure 2. Features for a given user include name, description, tweet, relationship, and profile image. Each classifier/model takes one or more features as input and predicts the probability of each role (i.e., brand, female, and male). Features and their details in each classifier/model are shown in Table 2. We utilized

[1]GitHub link: https://github.com/liuqingli/TwiRole

Table 1. An overview of the twelve tweet collections, across four disaster types

Type	Collection	Starting (UTC)	# of tweets	# of cleaned tweets
School Shooting	Sandy Hook Elementary School shooting	12/14/2012 14:40:00	100,833	97,283
	Stoneman Douglas High School shooting	02/14/2018 19:27:00	22,441	22,321
	Umpqua Community College shooting	10/01/2015 17:48:00	17,930	17,821
Bombing	Boston Marathon bombing	04/15/2013 18:49:00	220,221	211,142
	San Bernardino attack	12/02/2015 18:58:00	44,359	44,224
	Manchester Arena bombing	05/22/2017 21:31:00	6,119	6,105
Earthquake	Nepal earthquake	04/25/2015 06:11:00	677,067	671,323
	Japan earthquake	03/11/2011 05:46:00	644,814	566,627
	Taiwan earthquake	02/05/2016 19:57:00	49,052	48,894
Hurricane	Hurricane Sandy	10/22/2012 00:00:00	2,528,523	2,399,334
	Hurricane Matthew	09/28/2016 00:00:00	1,092,684	1,088,212
	Hurricane Florence	08/31/2018 00:00:00	639,888	636,281

an existing third-party dataset (Kaggle 2016) to train and test TwiRole, and also evaluated it on the users extracted from our disaster collections. TwiRole performs better than other existing models on the Kaggle dataset, and its overall accuracy is about 90%.

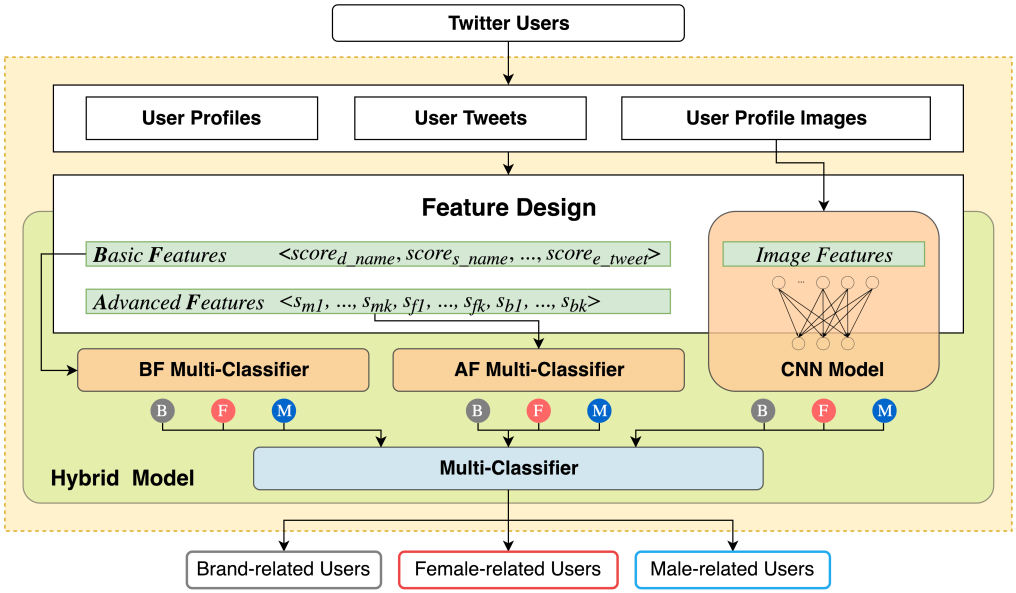


Figure 2. TwiRole is a hybrid model consisting of four components. The BF multi-classifier takes the basic features from the user profiles and tweets as input. The AF multi-classifier focuses on the k-top words in user tweets. The CNN works on the user profile images. The final multi-classifier takes the output of the above three modules as input during training and testing.

Mood Detection

We used a pre-trained RNN model (Colneriĉ and Demsar 2018) for predicting Ekman's emotions (Ekman 1992) from tweets, which outperforms several traditional machine learning methods (e.g, SVM, Naive Bayes, Random Forest). The F1 score mentioned in their paper is about 70%, leading to an approximate emotion analysis. The model takes each tweet as input and predicts the score for each of six basic emotions (i.e., anger, disgust, fear, happiness, sadness, and surprise). In our study, as a simple start, we focus on three moods: fear, sadness, and surprise. We assume these are common feelings during disasters.

FINDINGS

Disaster Patterns

For each disaster collection, we calculated the number of tweets posted per hour during the time window of the event. Then we applied min-max normalization to convert the number of hourly tweets to a scale between 0 and 1

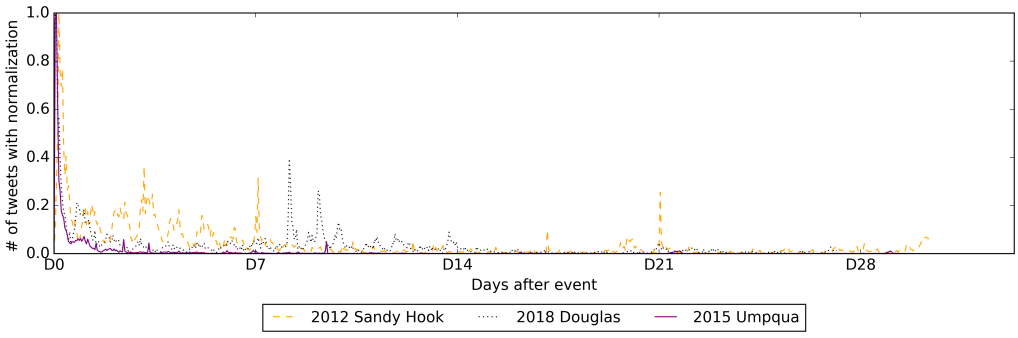
Table 2. Feature Types and Details in TwiRole

No.	Feature Type	Feature Detail	No.	Feature Type	Feature Detail
BF1	*name*	display name screen name	BF3	*relationship*	Twitter Follower-Friend score
			BF4	*profile image*	brightness
BF2	*description*	first-person score term frequency	BF5	*tweet*	first-person score interjection score emotion score
AF	*tweet*	k-top words	CNN	*profile image*	hidden in image

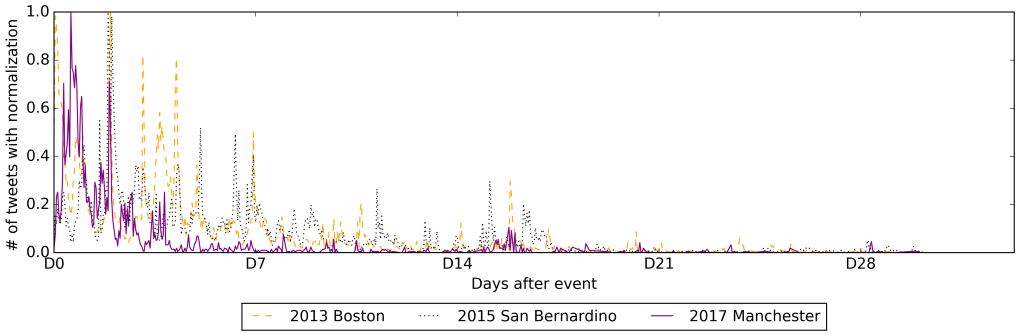
for inter-comparison. Different colors represent different collections in each disaster type. Figures 3a to 3d show the collection timelines across different disaster types.

Figure 3 illustrates that each type of disaster has a pattern that differs from the others. These patterns can also help us better understand user mood changes.

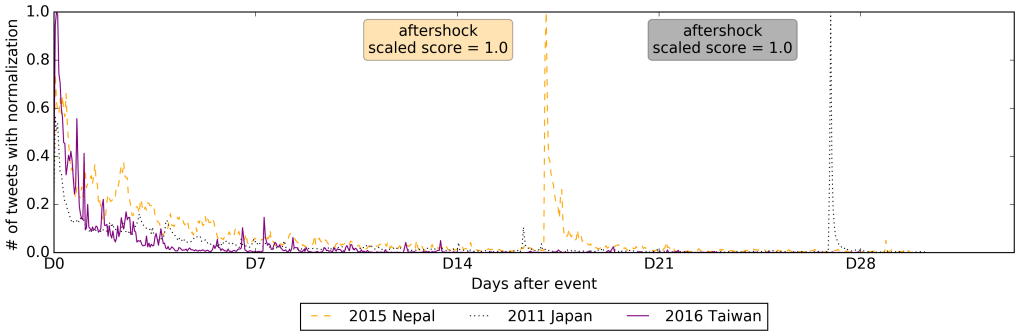
- *School Shooting*: School shootings are not as complicated, among man-made disasters, as bombings. The number of hourly tweets dropped to a low level just one or two days after a shooting. However, further along in the timeline, there are still some smaller peaks, e.g., corresponding to subsequent information releases or discoveries.
- *Bombing*: Each bombing timeline demonstrates highly variable numbers of tweets during the subsequent week. Tweets in significant numbers were posted even two or three days after the incident, which indicates that users paid close attention to information about the disaster.
- *Earthquake*: Twitter users posted many tweets, shown by a peak, when an earthquake occurred, and then the number of tweets gradually reduced over time. Later, when a massive aftershock occurred, another greater peak appeared, followed by a rapid reduction different from that observed after the original event.
- *Hurricane*: As a progressive natural disaster, each hurricane has a well-recognized timeline that approximates a normal distribution. We can roughly distinguish its stages and estimate the time when it hit land and caused severe damage. Moreover, the day-night periodicity in tweet number variations is more significant than for other types of disasters.



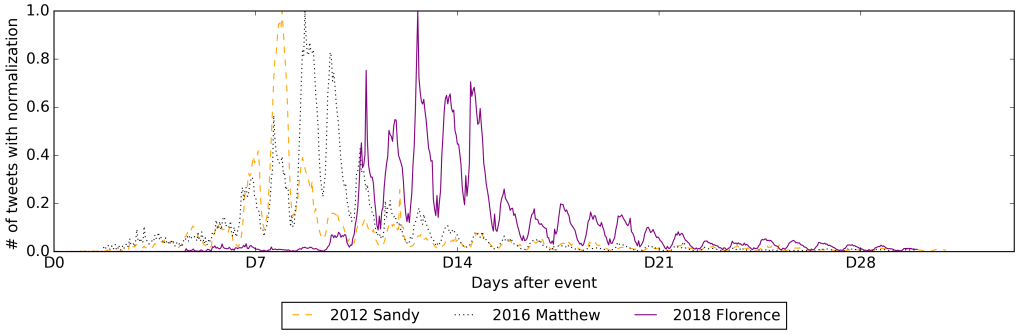
(a) School Shooting



(b) Bombing



(c) Earthquake



(d) Hurricane

Figure 3. Number of tweets (scaled) per hour for different types of disasters

User Distribution

We randomly selected at most 10,000 users from each disaster collection; the total across all collections was 107,323 users. Some accounts were deactivated or protected. Finally we utilized TwiRole to detect a user's role for 102,597 users (95.6% of 107,323 users). Afterward, we calculated the fraction of each role in each collection. The results (Brand: 0.4737 ± 0.0093; Female: 0.2124 ± 0.0098; Male: 0.3139 ± 0.0085) indicate that the distribution of users is relatively consistent among all disasters, as shown in Figure 4. Brand users are the primary group who might publish information or deliver messages, while male users participated more actively than female users in our selected disasters.

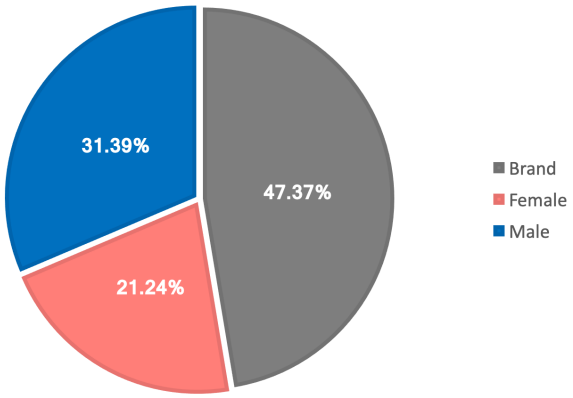


Figure 4. User distribution totals across all disasters

Bots are worth exploring and we applied Botometer for detection. Due to the rate limit, we detected 150 sampled users for each collection and calculated the percentage of bot users. The result (0.0694 ± 0.0270) indicates that only a small number of users are bots, so they have little impact on our results.

Mood Changes in All Users

We randomly sampled at most 100,000 tweets from each disaster collection and predicted the mood scores (i.e., fear, sadness, and surprise) of each tweet with the pre-trained RNN classifier. The scores of each mood were accumulated and divided by the total number of tweets in each collection. Figure 5 shows the average scores of the three moods in our collections.

Fear is the dominant feeling in eight out of the twelve disasters, which is consistent with our expectation. After the Boston bombing in 2013, users posted more fear tweets and expressed their feelings with words: *fear*, *afraid*, *terror*, *deadly*, or *scared*. During Hurricane Matthew in 2016, the fear words include *fear*, *scary*, *terrifying*, *frightening*, and *threatening*.

Twitter users show more fear and surprise than sadness in ten collections. The two counter-examples are school shootings, where sadness is the common mood. Users felt great sadness for the children and students who died or were injured in those massacres, and showed their feelings with sad words or phrases like *R.I.P*, *heart goes out*, *condolence*, *heart is broken*, and *depressed*.

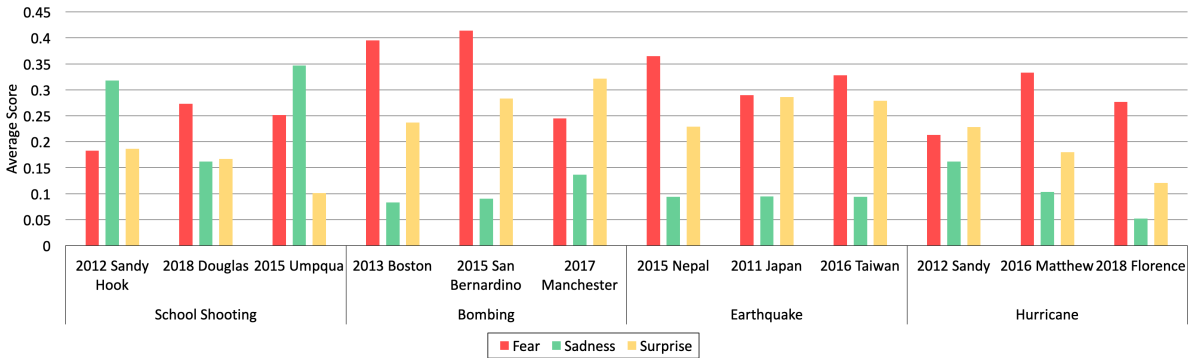


Figure 5. Average scores of fear, sadness, and surprise in different types of disasters

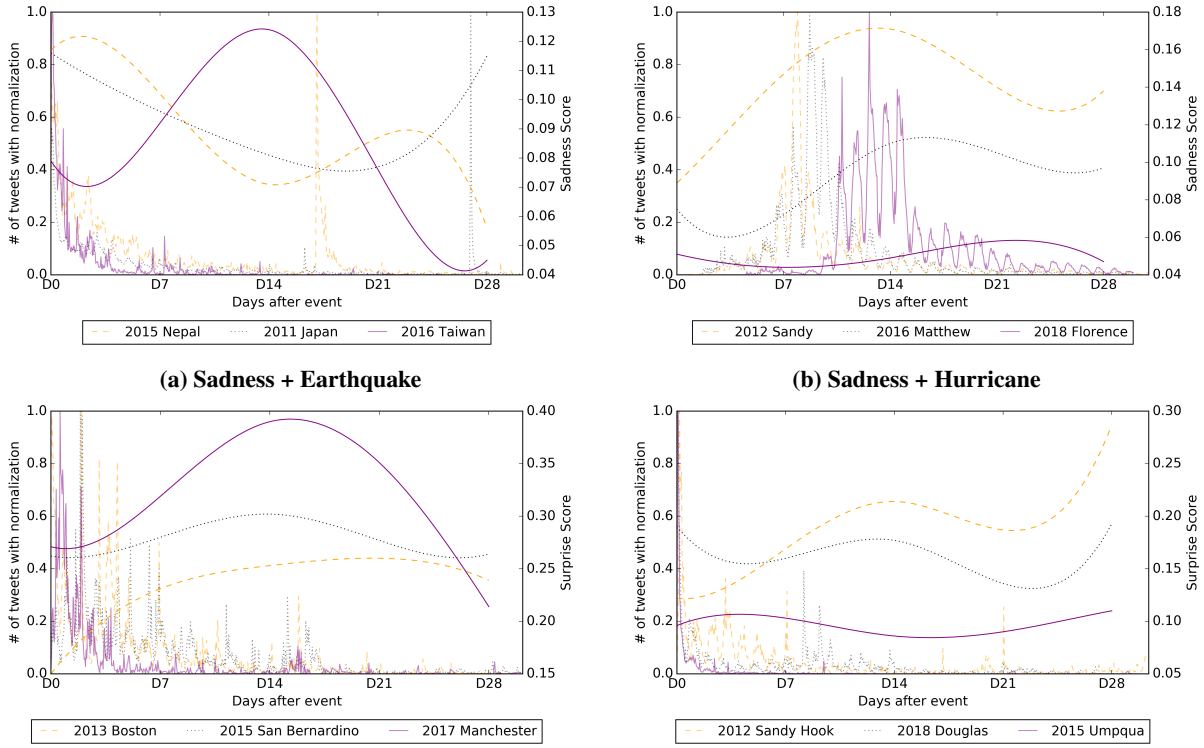
To explore further, we calculated the average score of each mood on the first day of each disaster and in every week after that. We selected two moods and two types of disasters for each mood, and showed changes over time with the corresponding tweet timelines, in Figures 6a through 6d. Figure 6a illustrates the sadness change in the earthquake disasters. The sadness score peaked two weeks after the main shock in Taiwan, while the aftershock played an important role in the Japan and Nepal earthquakes, leading to an increase in sadness. Figure 6b displays the sadness change in the selected three hurricanes. The sadness scores peaked about one week after the tweet count peaks of the three tweet timelines. Figure 6b also supports a quantitative comparison of the impacts of the three hurricanes. Users felt sadder in Hurricane Sandy, since it was the fourth-costliest hurricane in U.S. history, while Hurricane Florence made landfall as a weakened Category 1 hurricane, accompanied by a low sadness score.

The peaks in surprise were delayed by two or three weeks, for the bombing disasters shown in Figure 6c; we discuss more about mood delays below. As Figure 6d indicates, for school shootings, the scores of surprise were still increasing one month after the disasters, especially for the Sandy Hook Elementary School shooting (2012) and the Douglas High School shooting (2018). After browsing through users' tweets, we noted that users posted tweets like "*The Sandy Hook shooting was a hoax?!*" and "*I find it very odd two of the sandy hook funds were created before the shooting*" after the former shooting event, while they tweeted "*Who's Behind the Real Scandal*" about the latter event.

Mood Changes for Different Roles of Users

Based on the user and mood classification results, we enriched each tweet collection with user roles and mood scores, analyzed the mood changes among different role-related users, and carried out two case studies. Each sub-figure in Figure 7 illustrates the mood change across brand, female, and male users in one specific disaster, with its corresponding tweet timeline. Then, for each case study, we sorted the tweets according to mood score, and presented the surprise value for the k-th (k=1, 10, 20, 30) ranking tweets, for all three roles. Finally, we give the texts of some sampled tweets in Tables 3 and 4.

- *Case Study 1*: Surprise change in 2011 Japan Earthquake
  Figure 7a shows that the surprise score of male users had a significant increase after the aftershock, compared with the scores of brand and female users. The ranked k-th surprise scores also show male users were more surprised than brand users, while female users were relatively calm during that period.



(a) Sadness + Earthquake

(b) Sadness + Hurricane

(c) Surprise + Bombing

(d) Surprise + School Shooting

Figure 6. Mood changes (smoothed) for different types of disasters

Table 3. Ranked k-th surprise score comparison and sample tweets from male users in 2011 Japan Earthquake

	Surprise Score		
k	**Brand**	**Female**	**Male**
1	0.993	0.938	0.996
10	0.899	0.775	0.959
20	0.866	0.664	0.925
30	0.818	0.570	0.880

Sample tweets from male users with high surprise scores
japan had another earthquake? #idontbelieveyou
Japan just had another earthquake. WHHAAAAAAAAA?!?
Mother nature #idontbelieveyou another earthquake Japan?
Another earthquake in Japan! #wow
There was another earthquake in Japan?!?! OMG #PRAYFORJAPAN

- *Case Study 2*: Fear change in 2012 Hurricane Sandy
  Figure 7b shows the divergence of fear scores among different roles that appeared during the last week of the one-month time window. Here, brand users expressed more fear, and the fear scores of female and male users decreased at the same time. From the sample tweets, we noticed that brand users posted fear-related tweets regarding the aftermath of the destructive hurricane.

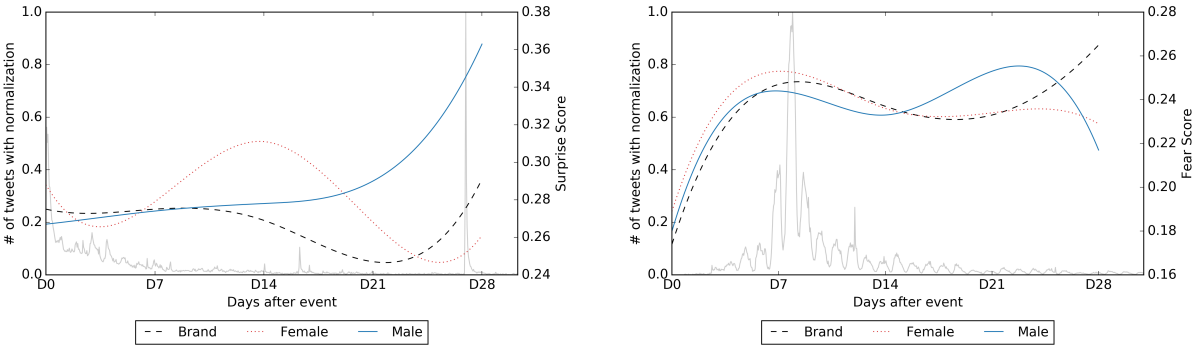
Table 4. Ranked k-th fear score comparison and sample tweets from brand users in 2012 Hurricane Sandy

	Fear Score		
k	**Brand**	**Female**	**Male**
1	0.999	0.991	0.996
10	0.875	0.720	0.848
20	0.789	0.537	0.733
30	0.728	0.441	0.635

Sample tweets from brand users with high fear scores
Haiti fears food crisis in Hurricane #Sandy's aftermath
Hurricane Sandy 2012: What a nightmare!! Lack of power, gas rationing...
Gas Shortage In New York After Hurricane Sandy Caused By Poor Policy
Terrifying Note Left Behind By a New Jersey Man In Hurricane #Sandy...
#Forbes Obviously the destruction caused by Hurricane Sandy posed a risk...

EVALUATION OF TWIROLE

Our new tool TwiRole has been used to predict the role of a Twitter user. To assuage concerns regarding the accuracy of the user classification predictions, we report on an evaluation of that tool. We utilized 10-fold cross-validation to evaluate TwiRole on an existing third-party dataset with gold standard labels. Further, we randomly selected 150 users from our disaster collections, and labeled user roles by hand, for a further evaluation of the prediction results of TwiRole.



(a) Surprise + 2011 Japan Earthquake **(b) Fear + 2012 Hurricane Sandy**

Figure 7. Mood changes (smoothed) among different roles of users in specific disasters

Metrics

We use a confusion matrix to calculate the recall (R), precision (P), and F1 score for each role. For a certain role r, the three values are computed as:

$$\begin{aligned} Recall_r &= \frac{\text{\# of users correctly identified as } r}{\text{\# of users labeled as } r}, \\ Precision_r &= \frac{\text{\# of users correctly identified as } r}{\text{\# of users predicted as } r}, \\ F1_r &= \frac{2 * Recall_r * Precision_r}{Recall_r + Precision_r} \end{aligned} \tag{1}$$

The performance of TwiRole is reflected in the overall accuracy; see Equation 2.

$$Accuracy = \frac{\sum_r (\text{\# of users correctly identified as } r)}{\sum_r (\text{\# of users labeled as } r)} \tag{2}$$

Results

First, we compare TwiRole with Ferrari et al.'s work (Ferrari et al. 2017) on the same third party dataset, since they also categorized Twitter users into the same three classes. The classification results are shown in Table 5. Their model has an advantage in identifying the male-related users, where their F1 score is 0.947 while ours is 0.903. But TwiRole performs better in detecting both female-related ($F1_{female} = 0.908$) and brand-related users ($F1_{brand} = 0.885$), and the overall accuracy ($Acc = 0.899$) is higher than with Ferrari et al.'s approach ($Acc = 0.865$). In addition, the prediction results of our model are more balanced across different roles, because the difference in F1 score is only 0.023 in TwiRole while it is 0.136 for Ferrari et al.

Table 5. Classification results of TwiRole and Ferrari et al.'s work

Tool	Brand			Female			Male			Acc
	R	P	F1	R	P	F1	R	P	F1	
TwiRole	**0.891**	**0.879**	**0.885**	**0.920**	**0.897**	**0.908**	0.885	0.922	0.903	**0.899**
Ferrari et al., 2017	0.837	0.786	0.811	0.806	0.857	0.831	**0.948**	**0.946**	**0.947**	0.865

Table 6. Classification results of TwiRole on disaster collections

Tool	True Label	# of users	Predict			Accuracy
			Brand	Female	Male	
TwiRole	Brand	50	41	6	3	82%
	Female	50	6	38	6	76%
	Male	50	10	3	37	74%

Second, using our disaster collections, we randomly chose 50 users labeled by TwiRole in each class and checked their roles manually by browsing their Twitter pages. Table 6 lists the manual checking results and the accuracy of prediction in each role. The overall accuracy of TwiRole is about 77%, which is satisfactory in our situation, where it is used to describe mood changes among tweeters.

DISCUSSION

As is mentioned in the Findings section, mood delays appear in some disasters. For instance, sadness maximum values were delayed one week after the peak counts in tweet timelines for hurricanes, while surprise score has a delay of two or three weeks for the bombing disasters. Accordingly, we examined mood changes over four weeks in all of our twelve collections, to check whether mood delay is a widespread phenomenon in disasters and is different among moods. For each mood, we compared its score on the first day with the score in each of the following four weeks. Table 7 lists the occurrences of the peaks of moods in different periods.

Table 7. Mood peak occurrences in different periods of time among all twelve disasters

Moods	Number of peaks occurred on / in					
	Day 0	Week 1	Week 2	Week 3	Week 4	Total
fear	3	2	4	0	3	12
sadness	7	0	2	1	2	12
surprise	1	3	2	3	3	12

The peaks of fear occurred on the first day in three out of the twelve collections (i.e., 2017 Manchester Arena bombing, 2015 Nepal earthquake, and 2012 Hurricane Sandy), while others can be found in the following weeks. Sadness peaks could be spotted on the first day in seven disasters, while others appeared in the next few weeks. For the surprise mood, the first-day peak only existed in one disaster (i.e., 2016 Hurricane Matthew); other peaks were distributed evenly over the weeks. Based on the mood peak distribution, we found that the sadness delay is shorter than the other two moods, which indicates that people tend to show their sadness feelings while facing a disaster right after its occurrence. In contrast, fear and surprise moods are likely to be delayed, as disasters and their reporting develop or unfold.

CONCLUSION

Focusing on patterns and mood changes during disasters on Twitter, we built twelve tweet collections with four disaster types: *school shooting*, *bombing*, *earthquake*, and *hurricane*. Then, we designed and implemented TwiRole to detect different roles of users, and used a pre-trained RNN model to predict moods (i.e., fear, sadness, and surprise) of tweets. Both user roles and mood scores were added to the data in the raw tweet collections to enrich the tweet representation.

Regarding analysis, we first investigated different types of disasters and found that each type has its own pattern. Next, based on the percentage of each role in our disasters, we concluded that brand users played an important role in disasters, while male users seemed more active than female users. Then, we worked on the mood changes at the event level and discovered that fear is the major feeling in most disasters, while sadness is dominant in two of the school shootings analyzed. By exploring each collection at the week level, we carried out a temporal analysis and discussed mood delays in disasters, where sadness is more time-sensitive than fear and surprise. Finally, two case studies illustrated that mood variation appears among users with different roles.

There are some limitations to our study that should be noted. The performance of the two classifiers might not be the best, in identifying users and moods, resulting in an approximate analysis. Three disasters in each type might not be enough for pattern analysis. We accumulated the mood scores of tweets, and it might not be the best approach to describe users' moods. In future work, we plan to add more disaster collections and improve the performance of TwiRole. We also will examine the analysis results on both local and distant populations, since the mood patterns might be different. Another improvement would be to explore the text information (e.g., frequent words, favorite topics) of tweets of users, which can assist in victim recovery in real-world emergencies.

ACKNOWLEDGMENT

Thanks go to the US NSF for its support of the Global Event and Trend Archive Research (GETAR) project, through grant IIS-1619028. We would also thank Ziqian Song and Xuan Zhang for their early work on TwiRole.

REFERENCES

Alam, F., Ofli, F., and Imran, M. (2018). "A Twitter Tale of Three Hurricanes: Harvey, Irma, and Maria". In: *ISCRAM*.

Alowibdi, J. S., Buy, U. A., and Yu, P. (2013a). "Empirical Evaluation of Profile Characteristics for Gender Classification on Twitter". In: *Machine Learning and Applications (ICMLA), 12th International Conference on*. Vol. 1. IEEE, pp. 365–369.

Alowibdi, J. S., Buy, U. A., and Yu, P. (2013b). "Language Independent Gender Classification on Twitter". In: *Proceedings of the IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining*. ACM, pp. 739–743.

Artwick, C. G. (2014). "News sourcing and gender on Twitter". In: *Journalism* 15.8, pp. 1111–1127.

Bamman, D., Eisenstein, J., and Schnoebelen, T. (2014). "Gender identity and lexical variation in social media". In: *Journal of Sociolinguistics* 18.2, pp. 135–160.

Burger, J. D., Henderson, J., Kim, G., and Zarrella, G. (2011). "Discriminating Gender on Twitter". In: *Proceedings of the conference on empirical methods in natural language processing*. Association for Computational Linguistics, pp. 1301–1309.

Caragea, C., Squicciarini, A. C., Stehle, S., Neppalli, K., and Tapia, A. H. (2014). "Mapping Moods: Geo-Mapped Sentiment Analysis During Hurricane Sandy". In: *ISCRAM*.

Ciot, M., Sonderegger, M., and Ruths, D. (2013). "Gender Inference of Twitter Users in Non-English Contexts". In: *Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing*, pp. 1136–1145.

Colneriĉ, N. and Demsar, J. (2018). "Emotion Recognition on Twitter: Comparative Study and Training a Unison Model". In: *IEEE Transactions on Affective Computing*.

Daas, P. J., Burger, J., Le, Q., Bosch, O. ten, and Puts, M. J. (2016). *Profiling of Twitter users: a big data selectivity study*. Tech. rep. Discussion paper 201606, Statistics Netherlands.

Ekman, P. (1992). "An argument for basic emotions". In: *Cognition & emotion* 6.3-4, pp. 169–200.

Ferrari, F., Jasuja, A., Seth, M., and Sharma, R. D. (2017). *Gender Inference Based On Twitter Profiles*. https://csewe-b.ucsd.edu/classes/wi17/cse258-a/reports/a119.pdf.

Fischer, D., Schwemmer, C., and Fischbach, K. (2018). "Terror Management and Twitter: The Case of the 2016 Berlin Terrorist Attack". In: *ISCRAM*.

Fortmann-Roe, S. (2013). "Effects of hue, saturation, and brightness on color preference in social networks: Gender-based color preference on the social networking site Twitter". In: *Color research & application* 38.3, pp. 196–202.

Geng, L., Zhang, K., Wei, X., and Feng, X. (2017). "Soft Biometrics in Online Social Networks: A Case Study on Twitter User Gender Recognition". In: *Applications of Computer Vision Workshops (WACVW), 2017 IEEE Winter*. IEEE, pp. 1–8.

Herfort, B., Schelhorn, S.-J., Albuquerque, J. P. d., Zipf, A., et al. (2014). "Does the spatiotemporal distribution of tweets match the spatiotemporal distribution of flood phenomena? A study about the River Elbe Flood in June 2013". In: *ISCRAM*.

Kaggle (2016). *Twitter User Gender Classification*. https://www.kaggle.com/crowdflower/twitter-user-gender-classification.

Kavanaugh, A., Sheetz, S. D., Hassan, R., Yang, S., Elmongui, H. G., Fox, E. A., Magdy, M., and Shoemaker, D. J. (2013). "Between a Rock and a Cell Phone: Communication and Information Technology Use during the 2011 Uprisings in Tunisia and Egypt". In: *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)* 5.1, pp. 1–21.

Lasorsa, D. (2012). "Transparency and Other Journalistic Norms on Twitter". In: *Journalism Studies* 13.3, pp. 402–417.

Lee, S., Elsherbiny, N., and Fox, E. A. (2012). "A Digital Library for Water Main Break Identification and Visualization". In: *Proceedings of the 12th ACM/IEEE-CS joint conference on Digital Libraries*. ACM, pp. 335–336.

Levi, G. and Hassner, T. (2015). "Age and Gender Classification Using Convolutional Neural Networks". In: *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops*, pp. 34–42.

Li, J., Ritter, A., and Hovy, E. (2014). "Weakly Supervised User Profile Extraction from Twitter". In: *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics*. Vol. 1, pp. 165–174.

Liu, W. and Ruths, D. (2013). "What's in a Name? Using First Names as Features for Gender Inference in Twitter." In: *AAAI Spring Symposium: Analyzing Microtext*. Vol. SS-13-01. AAAI Technical Report. AAAI.

Moreno, A., Garrison, P., and Bhat, K. (2017). "WhatsApp for Monitoring and Response during Critical Events: Aggie in the Ghana 2016 Election". In: *ISCRAM*.

Mottl, D. (2018). *GetOldTweets3*. https://github.com/Mottl/GetOldTweets3.

Nagy, A. and Stamberger, J. (2012). "Crowd Sentiment Detection during Disasters and Crises". In: *ISCRAM*, pp. 1–9.

Neppalli, V. K., Medeiros, M. C., Caragea, C., Caragea, D., Tapia, A. H., and Halse, S. E. (2016). "Retweetability Analysis and Prediction during Hurricane Sandy". In: *ISCRAM*.

Nilizadeh, S., Groggel, A., Lista, P., Das, S., Ahn, Y.-Y., Kapadia, A., and Rojas, F. (2016). "Twitter's Glass Ceiling: The Effect of Perceived Gender on Online Visibility". In: *ICWSM*, pp. 289–298.

Norcross, J. C., Guadagnoli, E., and Prochaska, J. O. (1984). "Factor structure of the Profile of Mood States (POMS): two partial replications". In: *Journal of Clinical Psychology* 40.5, pp. 1270–1277.

Pennacchiotti, M. and Popescu, A.-M. (2011a). "A Machine Learning Approach to Twitter User Classification". In: *ICWSM*, pp. 281–288.

Pennacchiotti, M. and Popescu, A.-M. (2011b). "Democrats, Republicans and Starbucks Afficionados: User Classification in Twitter". In: *Proceedings of the 17th ACM SIGKDD international conference on Knowledge discovery and data mining*. ACM, pp. 430–438.

Plutchik, R. (1990). "Emotions and psychotherapy: A psychoevolutionary perspective". In: *Emotion, psychopathology, and psychotherapy*. Elsevier, pp. 3–41.

Purohit, H. and Chan, J. (2017). "Classifying User Types on Social Media to inform Who-What-Where Coordination during Crisis Response". In: *ISCRAM*.

Rao, D., Yarowsky, D., Shreevats, A., and Gupta, M. (2010). "Classifying Latent User Attributes in Twitter". In: *Proceedings of the 2nd international workshop on Search and mining user-generated contents*. ACM, pp. 37–44.

Schulz, A., Thanh, T. D., Paulheim, H., and Schweizer, I. (2013). "A Fine-Grained Sentiment Analysis Approach for Detecting Crisis Related Microposts". In: *ISCRAM*.

Shen, S., Cheng, C., Song, C., Yang, J., Yang, S., Su, K., Yuan, L., and Chen, X. (2018). "Spatial distribution patterns of global natural disasters based on biclustering". In: *Natural Hazards* 92.3, pp. 1809–1820.

Vicente, M., Batista, F., and Carvalho, J. P. (2015). "Twitter gender classification using user unstructured information". In: *Fuzzy Systems (FUZZ-IEEE), 2015 IEEE International Conference on*. IEEE, pp. 1–7.

Wang, Y., Feng, Y., Luo, J., and Zhang, X. (2016). "Voting with Feet: Who are Leaving Hillary Clinton and Donald Trump". In: *Multimedia (ISM), 2016 IEEE International Symposium on*. IEEE, pp. 71–76.

Wendland, J., Ehnis, C., Clarke, R., and Bunker, D. (2018). "Sydney Siege, December 2014: A Visualisation of a Semantic Social Media Sentiment Analysis". In: *ISCRAM*.

Wilensky, H. (2014). "Twitter as a Navigator for Stranded Commuters during the Great East Japan Earthquake". In: *ISCRAM*.

Yang, S., Chung, H., Lin, X., Lee, S., Chen, L., Wood, A., Kavanaugh, A. L., Sheetz, S. D., Shoemaker, D. J., and Fox, E. A. (2013). "PhaseVis: What, When, Where, and Who in Visualizing the Four Phases of Emergency Management Through the Lens of Social Media". In: *ISCRAM*.

Filtering Images Extracted from Social Media in the Response Phase of Emergency Events

Sara Barozzi
Politecnico di Milano, Milan, Italy,
sara.barozzi@mail.polimi.it

Amudha Ravi Shankar
University of Geneva, Geneva, Switzerland,
amudha.ravishankar@unige.ch

Jose Luis Fernandez-Marquez
University of Geneva, Geneva, Switzerland,
JoseLuis.Fernandez@unige.ch

Barbara Pernici
Politecnico di Milano, Milan, Italy,
barbara.pernici@polimi.it

ABSTRACT

The use of social media to support emergency operators in the first hours of the response phases can improve the quality of the information available and awareness on ongoing emergency events. Social media contain both textual and visual information, in the form of pictures and videos. The problem related to the use of social media posts as a source of information during emergencies lies in the difficulty of selecting the relevant information among a very large amount of irrelevant information. In particular, we focus on the extraction of images relevant to an event for rapid mapping purpose. In this paper, a set of possible filters is proposed and analyzed with the goal of selecting useful images from posts and of evaluating how precision and recall are impacted. Filtering techniques, which include both automated and crowdsourced steps, have the goal of providing better quality posts and easy manageable data volumes both to emergency responders and rapid mapping operators. The impact of the filters on precision and recall in extracting relevant images is discussed in the paper in two different case studies.

Keywords

Rapid mapping, floods, information extraction, filtering, crowdsourcing

INTRODUCTION

During the first phases of crisis response after an emergency event such as a flood, a storm, or an earthquake, there is a need for creating awareness about the ongoing event and for providing as much information as possible to the emergency operators. Social media are considered a potentially valuable source of information to support gathering information from people living near the event location or informed about it. Several initiatives based on social media have been proposed, as well as tools to manage automatically the large amounts of data produced by social media in those cases (Imran et al. 2015), that can reach hundreds of thousands or even millions of posts related to the event within hours. It is well known that among this large amount of data, only a small amount of it consist of valuable information. For instance, in an analysis of Dresden floods in 2013 (Fohringer et al. 2015), from 15 millions of tweets in the flood period, only 5 images were considered useful to estimate water levels in the affected area.

Very recently, in (Alam et al. 2018) the extraction of relevant images from social media has been discussed with the goal of providing only relevant images about the event, eliminating duplicates and using supervised machine learning techniques to assess the damage's intensity in the area of interest. In fact, the concept of relevance is heavily dependent on the task to be performed, be it an assessment of water levels as in (Fohringer et al. 2015), or an assessment of the intensity of damage as in (Alam et al. 2018).

In the present paper, we focus on the task of extracting images which are useful for rapid mapping purposes, for a fast provision (hours-days) of geospatial information to support emergency management activities immediately following an emergency event.

The goal of this paper is to discuss how information retrieved from social media posts extracted from Twitter, can provide a visual evidence about a disaster.

In particular, we discuss how different filtering techniques can support the selection of the images which are relevant to an event from the large number of incoming social media posts. The different filtering options, which include automatic filtering and crowdsourcing, are presented and analyzed in detail, focusing mainly on two parameters: precision and recall. Precision allows us to provide the operators with images which are really relevant to the event, while recall evaluates how much a filter could result in a loss of contents, since it filters our possibly useful images.

The paper is structured as follows. First, we discuss the state of the art, then we introduce the crisis maps created in the E2mC project and how visual information can be retrieved from social media. Then we discuss possible filters to reduce the amount of irrelevant information provided to the volunteers for crowdsourcing and to emergency rapid mapping operators. The evaluation of the effect of filters in terms of precision and recall is then performed in two cases studies, discussing possible threats to validity and future work.

RELATED WORK

Information systems for emergencies have been rapidly developing since the first successful experiences with Ushahidi[1] (Goldstein and Rotich 2008) and its use in the Haiti earthquake [2].

Several other initiatives focus also on real time collection of information, such as in SensePlace, focusing on near real-time access for big streaming data (MacEachren et al. 2011; Pezanowski et al. 2018) and TWINE (Nozza et al. 2017) for real-time analysis of posts.

Many studies have been carried out in the last years regarding the extraction of relevant information through the analysis of the textual content of the posts published during disasters. On the other side, the visual contents have not been studied that much. (Peters and Albuquerque 2015) have demonstrated that the images extracted can increase awareness on the situation and that they can be indicators of the relevance of the post in which they are contained; however some authors underlined that to obtain, manage and analyze them automatically is complex (Murthy et al. 2016). They reported an analysis of how the contents of the posted images change during the different phases of the disaster, by classifying them manually. (Gupta et al. 2013) tried to filter fake images extracted from social media during hurricane Sandy in 2012. Since they noted that traditional image analysis methods were difficult to apply, they used tweet-based features to create a Decision Tree classifier that reached the 97% of accuracy in detecting fake pictures. (Chen et al. 2013) built an automated classifier utilizing text, image and social context features to distinguish visually-relevant and visually-irrelevant tweets obtaining a macro F1 of 70.5%. Another recent work from (Alam et al. 2018) shows a combined use of human and machine computing to process social media images for damage assessment during a disaster. They propose a real-time social media image-processing pipeline where unwanted images are discarded through a deduplicating passage, based on perceptual hashing, and through a relevance filter, based on Convolutional Neural Networks architectures. The images are then labelled and classified by a crowd of volunteers and used to train the automatic machine classifier to assess the level of damages in area as severe, mild or none. Their results show that this approach can help to gain situational awareness during an ongoing event. They also show that filtering the images allows increasing the precision of the classification both of the human and of the machine system.

PRODUCING CRISIS MAPS IN E2MC

The E2mC project[3] has the goal of producing crisis maps for emergency events, to support rapid mapping activities performed by operators in Emergency Mapping Services (EMS) of Copernicus[4], the European initiative to provide timely and accurate information derived from satellite data and additional sources on the ground.

As described in (Havas et al. 2017), the E2mC platform is composed of a set of tools aimed to support the analysis of social media posts, extracted from Twitter, Flickr, and YouTube. The goal is to provide EMS rapid mapping operators with timely and relevant visual information extracted from posts. The processing of posts is performed in near real-time, as the event progresses. The starting point is a crawler that collects posts through the social media APIs. As most of the posts are not natively geolocated, in particular in Twitter and YouTube, crawling is followed by a geolocation tool, called CIME (Context-based Image extraction) (Francalanci et al. 2017), that localizes the posts as precisely as possible from the textual contents of each post using OpenStreetMap[5] as a gazeteer. Only the

[1] https://www.ushahidi.com/
[2] https://www.ushahidi.com/blog/2010/04/14/crisis-mapping-haiti-some-final-reflections
[3] https://www.e2mc-project.eu/
[4] https://www.copernicus.eu/services/emergency
[5] http://www.openstreetmap.org/

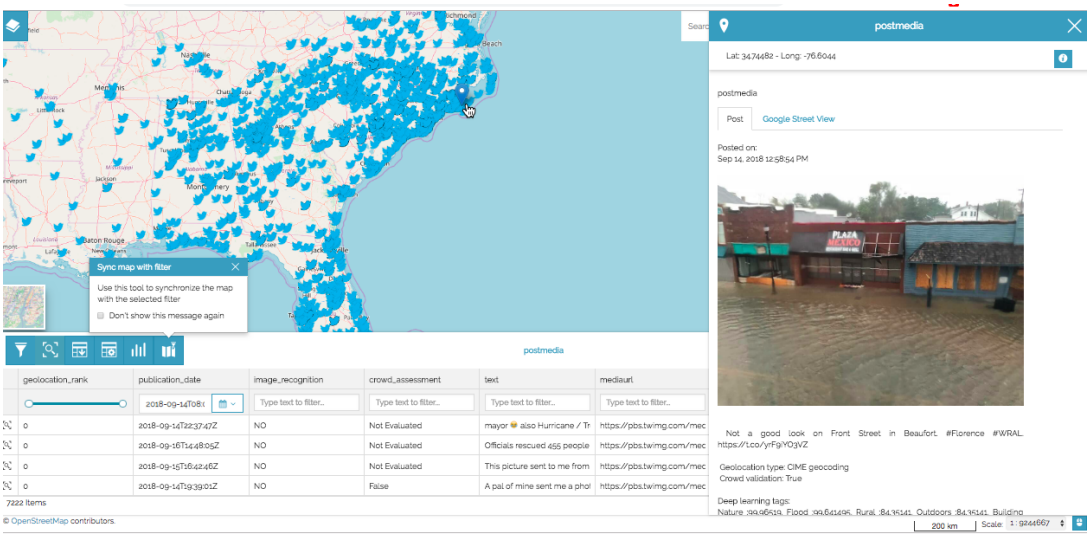


Figure 1. Witness user interface for the E2mC crisis maps

posts that contain an image or a video and are located at least at locality level (town or village) are retained for further analysis.

Figure 1 shows the webGIS interface developed in E2mC, called Witness. The Witness interface shown in the figure provides a crisis maps with located tweets (displayed in the center of their OSM location) and gives the possibility to show the contents of each tweet, accessing Twitter through its APIs. In addition, a set of possible manual filters is shown, to select localities at different levels of precision (from locality level down to precise points in the map), to examine only relevant tweets as evaluated from crowdsourcing, and to select only images detected as relevant to the specific type of event (e.g., floods).

The tweets are processed near-real time during the event, so that the classifications of the filters are incrementally populated.

In the present paper, we present different ways to reduce the number of tweets, and in particular using a set of filters which are discussed in detail in next section. Some of the filters illustrated in the following are part of the core E2mC platform, others, like the color and text filters, are proposed in the present paper and evaluated in the present work.

Two case studies are considered in the following parts of the paper, with datasets containing posts from Twitter which are geolocated at least at locality level and include an image: i) Southern England Floods in 2014 (corresponding to EMS activation number EMSR069, started on Feb. 10, 2014), consisting in 343 tweets, collected in the period February 10-14, 2014; ii) the Hurricane Florence over USA East coast in September 2018 (EMSR311), where the storm continually dumped heavy rain along coastal areas from September 13, 2018; in this case more than 28,500 posts have been crawled, of which we consider a data set of 2,940 posts collected in 24 hours on Sept. 13-14, 2018, from which we randomly sampled 301 posts for performing manual annotations for the analysis work presented in this paper. Both datasets are available on request from the authors.

FILTERS

During a disaster, the main problem is managing timeliness: for the operators it is necessary to have valuable information on the affected area in a short time. Images coming from social media can help in obtaining this information, but, on the other side, the volume of the data extracted may be too high to be managed within the short time frame they have. In addition, the data extracted is usually of low quality, since the images obtained from the crawling includes a high percentage of irrelevant information. Thus, it is necessary to send readily usable aggregated and cleaned data to the emergency rapid mapping operators and emergency responders. Consequently, many filters have been designed and analyzed to understand their potential in reducing the volume and improving the quality of the set of images available.

In the next subsections, we introduce a set of possible filters that can be applied to reduce the volume of posts with associated images to be provided to rapid mapping operators and we analyze their efficacy in improving the section of posts for rapid mapping. The following filters are considered in this work:

- Redundant information reduction
  - Duplicate reduction
  - Retweets elimination
- Image filtering
  - Colour-based filtering
  - Elimination of pre-event images
  - Face detection
  - Text detection
- Crowdsourcing
  - Crowd-sourced relevance tagging task

For each filter, a short description is provided in this section, illustrating the main characteristics, parameters, its effects, and time to be executed on a laptop HP Pavillon, with Intel Core i5 and 8GB RAM. In the following section, the filters are evaluated in the two case studies examined in this work.

Redundant information reduction

Duplicate reduction

During disasters, people use social media to post a huge amount of information, often sharing pictures they are seeing on pages of other users. Thus, the goal of this filter is to detect all the duplicates and near duplicates (that are pictures very similar to the original but with little modifications like addition of borders, colour enhancement and luminosity changes, addition of text, cropping), since they usually do not provide new information. However, it can happen that the same image is posted with different textual descriptions that may bring additional and useful information. The goal of the filter is to consider duplicate images only once in the filtered dataset.
The detection of duplicates can be implemented in different ways. The one adopted for the E2mC project provides the use of image hashing (in particular the perceptual hashing). Perceptual hashes are fingerprints of the pictures, created on the basis of the features and visual content of the images, so they are similar to each other if the images contain similar features. The perceptual hash is obtained through the Python library *phash* that is an open source software library. For all the pictures, the hash is computed and it is compared with the set of all the hashes found in the data set using the hamming distance, that is the number of positions at which the bits of the two strings of the hashes differ. If the distance between two hashes is lower than a certain threshold, then the pictures are considered duplicates. The threshold has been fixed to 15 since analyses on the data sets shown that this value guarantees the detection of a high number of duplicates while committing a low number of errors. This system has the advantage of being very fast (one second per image) since it just compares simple strings.
A modification that can be done to the previous algorithm consists in the addition of a feature detection system. A SIFT detector is used to identify the small characteristics of the pictures and compare them. These features are then compared with the feature of other images to assess if they match or not. With this improvement it is possible to detect more near-duplicates but the computation time increases 5 times.

Retweets elimination

A retweet is the re-post or the forward of the message posted by another user. During a disaster, the most impactful images or the funniest ones are retweeted several times. For the E2mC project it is important to understand if retweets bring new information or if they only increase the volume of the dataset. Retweets repost the same image and usually also the text is not changed, so they spread duplicated information. They can be identified by the initial "RT" at the beginning of the post's text, so they are easy to be recognized automatically. The goal of the analysis presented in this paper is to evaluate the impact of eliminating retweets on the resulting dataset, in terms of evaluating the loss of relevant images.

Figure 2. Examples of a white image, a black image and an image with peaks

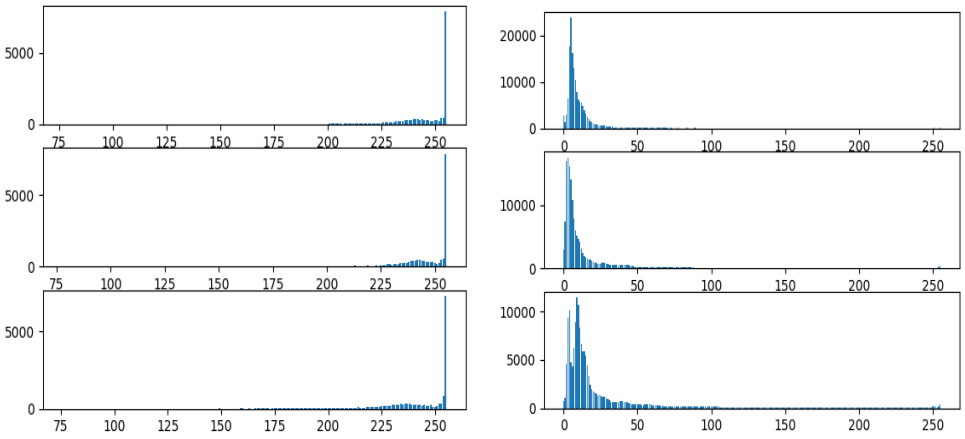


Figure 3. Histogram of a light image (left) and of a dark image (right)

Images filtering

Colour based filtering

The aim of this tool is the filtering of the images on the basis of their colours. During a disaster, pictures containing graphs, weather reports, jokes, texts are published, and they are not useful for disaster rapid mapping. This kind of images represent a huge source of noise during the analysis of the crawled posts. Therefore, three filters have been created to eliminate pictures that are too light, too dark or that contain graphs, drawings, not "taken photos". An example of these categories is reported in Figure 2.

The filter is based on an analysis of the image's intensity value histogram, that represents the distribution of the pixel values in the picture. Pictures that are very light have histograms shifted towards the higher values, while dark images have a histogram concentrated at the lower values. The difference is shown in Figure 3. There are three histograms because the levels of the RGB (red-green-blue) in the image are analyzed separately.
Pictures with graphs and drawings, that have a part of the picture of the same colour, present peaks of values in correspondence of these colour intensities. The difference between an image with peaks and a natural image can be seen in Figure 4.

For each filter a threshold is fixed to understand if the image should be discarded. The thresholds have been defined after an accurate analysis of the histogram of some test images. The thresholds for the "white" and "black" filters are based on the quartile (0,25,50,75,100 percentiles) subdivision of the histogram values. In fact, if the first quartile, that is 25, is high, it means that there is a concentration of pixel values towards the right side of the histogram, while if the third quartile, that is 75, is small, it means that values are concentrated in the left side of the histogram, meaning that a lot of pixels have a dark colour. In addition, the percentage of dark and light pixels in the image can be computed. Thus, if the first quartile is higher than 200 and the percentage of light pixels is higher than the 80% of the total values, the image is classified as 'white', while if the third quartile is lower than 35 and a percentage of dark pixels is higher than the 80% of the total values, the image is classified as 'black'. The images with peaks are, instead, identified as the images that have a total number of peaks higher than 3. A peak is found when the

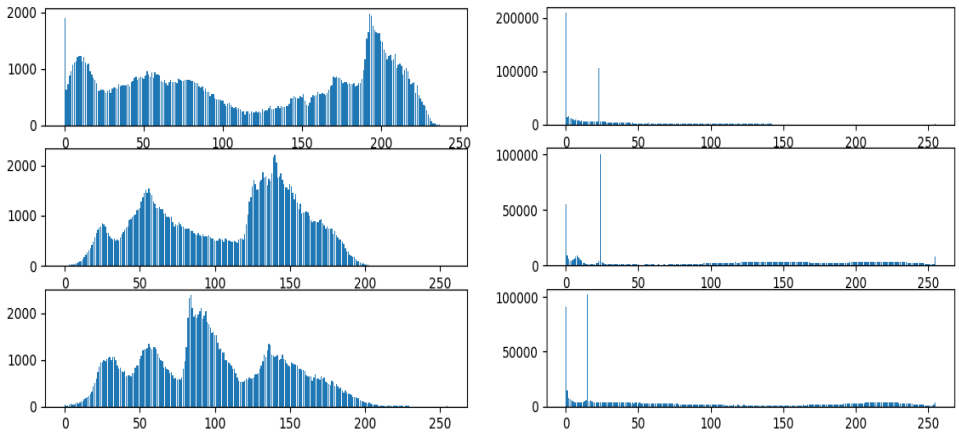


Figure 4. Example of a natural image histogram (left) and an image with peaks (right)

difference between the pixel intensity's before and after the analyzed pixel is high. This difference has been fixed to 3,500, but it can be lowered to create a filter that discards more images.
The classification of the images with these tools is fast and requires about 1 second for each picture.

Pre-event images

A problem that has been raised regarding the use of pictures posted in social media as a reliable source of information is the presence in datasets of pictures coming from previous events. These pictures can be mixed up with pictures of the current event, leading to the non-credibility of the whole dataset and to errors in the damage assessment of the affected area. The tool that has been used to face this issue is Google images[6].

This application offered by Google allows the user to search among all the pictures that have been posted on-line by keyword, by URL or uploading a picture to search all the similar ones present in the web. The parameters used to classify an image as being old are: (1) The presence in the Google results of older dates than the date of beginning of the disaster. (2) The presence in the results of pictures equal to the given one. (3) The presence of the searched image inside the website given as a result by the Google reverse image search.

Some problems limit the potentialities of this tool. There is a limitation on the call to the API that makes it necessary to add some waiting time in the process that increases the computational time of the algorithm. In addition, due to copyrights and recent policies on privacy, some pictures are no more freely available on the Internet. Because of this, some pictures coming from previous events may not be found.

Faces detection

Another kind of pictures that are present in the dataset during an emergency are the pictures with faces. These pictures often are not useful, such as jokes and selfies, but include also pictures extracted from television news reports, that in some cases could report useful information. Because of that, this filter should be used in case of overload of incoming pictures and when there is the need of reducing the dataset.
The tool, that exploits a built-in face classifier and detector, OpenCV[7], finds each face in the picture and draws around it a rectangle. Checking the number of faces found and the total area of the rectangle (or rectangles), it is possible to understand if the faces occupy the biggest part of the picture, thus meaning that it is not useful. A threshold value is needed to specify how many possible "face features" each candidate rectangle should have to consider it a face. In the current implementation, the threshold has been fixed to 8. This tool requires 0.5-1 seconds to evaluate each picture and it is very reliable. The limitation of this algorithm is related to the built-in cascade XML provided by OpenCV for the face recognition that is able to detect only frontal faces.

Text detection

Text detection can be used to reduce the volume of relevant images that arrive to geolocation crowdsourcing volunteers and to emergency rapid mapping operators, to provide a set of images easier to geolocate, an important characteristic when dealing with rapid mapping. In fact, the presence of words in an image can be related to road signs, license plates, shop signboards which are features that can help to find the place where the picture was taken.

[6]https://images.google.com/
[7]https://opencv.org/

Figure 5. Examples of relevant images with words detected in them

It is useful, in particular, in case of big datasets, since volunteers and emergency rapid mapping operators, that are overloaded with work, would prefer to see only the most relevant pictures.
The filter is a text detector created with the Python OpenCV's EAST text detector. The parameter that changes its performance is the probability that the area analyzed in the picture contains words. An area contains text if the probability is higher than a certain threshold, that has been fixed to 0.99 to ensure a reliable result in the finding of words. The time required to evaluate each picture is less than 2 seconds. Time can be reduced making the dimension of the picture under analysis smaller, but this operation would also decrease the precision of the tool.

Examples of the images extracted are reported in Figure 5. The EAST text detector has a limitation for the images with metal grills or meshes. In fact, it confounds tiny metal grills with words.

Crowdsourcing

Crowdsourcing is used in E2mC to both identify relevant posts and to validate and improve the precision of the geolocations generated by the CIME algorithm, with the help of volunteers. In the present paper we focus on crowdsourcing used for relevance tagging of the posts.

Crowdsourcing relevance tagging task

The selection of the pictures useful for creating disaster maps can be performed manually by a crowd of volunteers that evaluates the relevance of each image. Volunteers are asked to decide if a picture is relevant or not in a platform specifically created for the E2mC project, where the image and the related post are shown, as shown in Figure 6. The relevance value can be 1, when the image is considered useful and 0, when it is considered not useful. Each picture should be evaluated at least by 5 people to reduce the possibility of a wrong result by comparing the answers given by all the volunteers. In some cases of lack of time, the minimum number of results can be reduced, to process all the pictures in less time. The quality of the result given by the crowd, in this case, will decrease. Then the mean answer value is computed, and, if it is higher or equal to 0.8 (i.e. 4 out 5 volunteers considered the image relevant), the image is considered relevant. The time required to evaluate each picture is short, but the number of pictures that can be processed with this tool is not predictable, because it depends on the number of volunteers that participate in the project. From the case studies, each volunteer in the crowdsourcing can evaluate approximately 500 images per hour, however the effects of fatigue should also be considered, as discussed in (Purohit et al. 2018).

EVALUATION

In the present section we evaluate the illustrated filters, considering their effects on the goal of providing the rapid mapping operators with an informative set of images. Each filter can be considered a binary classifier that, depending on the value of a threshold, marks the images as 'negative' when they are classified as pictures to be eliminated because they are not relevant, or 'positive' if they should be kept, because they are useful for mapping purposes.

The result of the classification produced by each filter is then compared with the manual classification of relevance of each picture evaluated by two experts, to create confusion matrices that present the numbers of True Positive, True Negative, False Positive, False Negative. Thus, the filtering performance is evaluated in term of *precision*, i.e., the fraction of relevant posts among the retrieved posts, *recall*, i.e., the fraction of relevant posts that have been

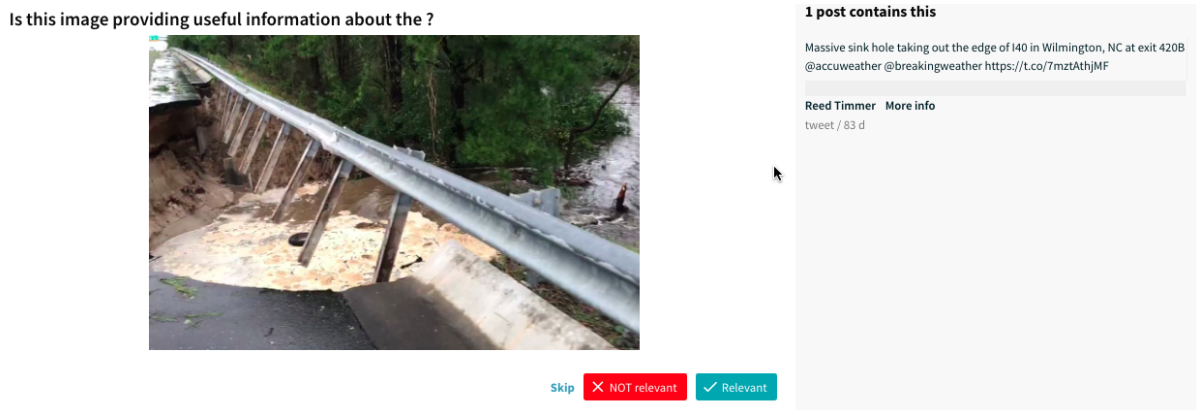


Figure 6. Crowd4EMS tool developed in E2mC

Table 1. Initial datasets expert evaluations

	UK flood		*Hurricane Florence*	
	Number of images	*Percentage*	*Number of images*	*Percentage*
Relevant	176	51.31%	38	12.62%
Not relevant	167	48.69%	263	87.38%

retrieved over the total amount of relevant posts, and the *percentages of relevant and non-relevant images discarded*. For each filter the mean percentage of reduction of the initial dataset and the precision gain after filtering is reported. The filters have been tested on two case studies, the floods that affected the Southern region of United Kingdom in 2014 and the Hurricane Florence in September 2018, which hit the North America East Coast. The first case study dataset is composed by 343 images that have been manually annotated, while for the second dataset a subset of 301 images has been used for the following analysis, manually annotating the relevance of the images by experts. For the analyses presented in this paper, random samples of the posts where manually annotated by two experts with the relevance of the images to the rapid mapping activity, as a basis for comparing the results obtained applying the different types of filters. Post selection is detailed in the following. The initial precision of the two datasets as evaluated by the experts and considered as ground truth are reported in Table 1.

Evaluation of redundant information reduction filters

Duplicates

Duplicated pictures have been detected in the two datasets with the *phash* technique. The algorithm shows limitations for both rotated and cropped images, which are not recognized as near duplicates. Duplicates are spread both between the relevant and non relevant images. The reduced precision of the final dataset in the set of hurricane Florence is due to the high percentage of duplicates between the relevant images. Table 2 summarizes the results.

Table 2. Duplicate filter results

	UK flood	*Hurricane Florence*
Precision	55.74%	9.70%
Recall	77%	60.53%
Relevant eliminated	23.00%	39.47%
Non relevant eliminated	35.33%	18.63%
Dataset reduction	28.86%	21.26%
Precision gain	+8.63%	-23.13%

Table 4. Colour filters results

	Filter white		*Filter black*		*Filter peaks*	
	UK flood	*Florence*	*UK flood*	*Florence*	*UK flood*	*Florence*
Precision	52.69%	13.38%	51.03%	12.50%	56.11%	14.81%
Recall	100%	100%	99.42%	97.37%	96.59%	84.21%
Relevant eliminated	0%	0%	0.58%	2.63%	3.41%	15.79%
Non relevant eliminated	5.39%	6.46%	1.78%	1.52%	20.36%	30.04%
Dataset reduction	2.62%	5.65%	1.17%	1.66%	11.66%	28.24%
Precision gain	+3.88%	+6.02%	+0.60%	-0.95%	+9.35%	+1.41%

Retweets

The filtering of the retweets has been applied on both datasets.The differences in the results on the two cases are due to the fact that hurricane Florence's dataset is characterized by a high percentage of retweeted posts, while for UK flood case they are less (see Table 3).

Table 3. Retweet filter results

	UK flood	*Hurricane Florence*
Precision	52.10%	6.86%
Recall	91%	32%
Relevant eliminated	9%	68%
Non relevant eliminated	11.38%	38.02%
Dataset reduction	9.91%	41.86%
Precision gain	+1.54%	-45.64%

Evaluation of image filters

Colour based

In Table 4 the results of the application of the three filters on the colour are reported. The low percentage of relevant images eliminated shows that they can be applied without discarding too many relevant pictures. The slightly higher value of relevant images eliminated by the "peak" filter on the hurricane Florence dataset is related to the scarce amount of relevant images in this dataset. Applying them one after the other can improve the quality of the final datasets and can eliminate high percentages of the non relevant images.

Images from previous events

The filter has been used on both the datasets. For the UK flood case study the algorithm was able to detect only one image considered relevant coming from a previous event. 11 not relevant images have been found that where posted from 2007 to the end of January 2014. In the case of hurricane Florence, no relevant images and 15 non-relevant images coming from previous events have been found.
This technique is not perfect and paid APIs would be needed to further improve it. Thus a faster and easier way to detect images from past events would be to create a database that collects the hashes of the viral and more repeated images of each event, to compare them with the new-coming images. This database could be implemented and tested when more case studies will be available.

Faces detection

The filter has been used on both the dataset showing that is useful to eliminate a part of the unwanted images without eliminating relevant ones (see Table 5.

Text detection

The filter has been applied to both the case studies' dataset to see how many images are discarded and if the images selected to be kept can be useful. In Table 6 the percentage of relevant and non-relevant images containing words

Table 5. Faces filter results

	UK flood	*Hurricane Florence*
Precision	53.66%	13.52%
Recall	100%	100%
Relevant eliminated	0%	0%
Non relevant eliminated	8.98%	7.60%
Dataset reduction	4.37%	9.63%
Precision gain	+4.58%	+7.13%

Table 6. Texts filter results

	UK flood	*Hurricane Florence*
Relevant with text	17.20%	9.97%
Non relevant With text	30.32%	62.46%
Reduction of the set of relevant	49.57%	21.05%

with respect to the whole dataset is reported to show that non-relevant images contain words more frequently than the relevant ones. Thus the last line of the table shows how much the set of relevant images would be reduced with this tool.

Evaluation of crowdsourcing activities

Crowdsourcing relevance tagging task

A crowd of volunteers has been used to evaluate both data sets. In the case of the Southern England floods dataset, the images have been evaluated five times by different members of the crowd, while in the case of hurricane Florence only once. This provokes a higher number of relevant images eliminated and lower number of non-relevant images discarded in this second case study (see Table 7). Anyhow the crowd filtering gives recall and precision values higher than any other filter for both case studies. The limitation of the tool is related to the human factor, since not always a sufficient number of persons are available to do these tasks when a disaster strikes.

Table 7. Crowdsourcing filter results

	UK flood	*Hurricane Florence*
Precision	96.93%	39.24%
Recall	88.76%	81.58%
Relevant eliminated	11.24%	18.42%
Non relevant eliminated	97.01%	81.75%
Dataset reduction	52.48%	73.75%
Precision gain	+88.91%	+210.94%

Evaluation of filters combinations

Some initial experimentation has been performed on the combination of the tools, in particular considering the configuration currently chosen in the E2mC project, which at the moment is adopting retweet filtering and crowdsourcing. The results have been evaluated using as ground truth an expert evaluation of the posts.

From the first experimental analyses, we gathered the following evidence:

- with the current E2mC configuration, retweets are filtered out and then a relevance task is performed by the crowd. We obtain an 80.11% recall and 2.99% False Positives in the UK flood case study and 69.92% recall and 9.09% False Positive rates in the case of Hurricane Florence, maintaining recall at a good level and with a limited number of false positives while reducing the manual effort. i.e., the resources needed to produce the images which are sent to the mapping operators for rapid mapping.

- Some filters appear to be highly correlated. For instance, black vs white filters are not correlated, while retweets and duplicates are highly correlated. Further investigation is needed to assess filter correlation in general.

THREATS TO VALIDITY

While for some of the filters, e.g., the colour filters, the recall and precision values have comparable values in the two case studies, in other cases they appear to be largely different, such as for instance for retweets. In future work, an estimation of these values could be derived case by case during different events, to study how to adapt thresholds and to estimate precision and recall accordingly.

Another aspect to be considered when combining different filters is that some of them are strongly correlated (e.g., the duplicates and the retweets filters). In those cases, the probability of joint occurrences for the two filters has also to be estimated, in order to be able to estimate the final precision and recall values for the combined filters. Ongoing work is analyzing the relationships between filters, to assess which ones are independent (such as for instance, it appears to be true in the pair white filter - duplicate filter) and the correlations patterns in correlated filters.

Finally, thresholds need to be fixed for each filter. They have been empirically estimated on the available case studies, therefore the values can not be considered valid for every kind of disaster. Also in this case further work is needed to be able to dynamically evaluate the appropriate thresholds for each filter given the type of emergency event and the number of available posts to be processed in real time.

CONCLUDING REMARKS

In this paper we have proposed a general approach for reducing the amount of irrelevant information extracted from social media during an emergency to support the activities of rapid mapping operators. As the quantity of posts can be variable in different events, due to their severity, their location, the availability of infrastructures after the event and the diffusion of social media, the aim is to support the choice of the best combination of filters depending on the characteristics of the on-going event. In future work, as the focus of this work has been on image analysis, we plan to analyze more in detail other types of filters, including also filters based on automatic image classification, being developed within the E2mC project. An adaptive tool combination and selection is also going to be studied in the future, to facilitate the rapid mapping operators activities, avoiding manual selection of filtering criteria, and aiming to generate a good combination of precision and recall in image selection. The aim of this work is to create an adaptive platform to select dynamically the filters and their thresholds, with an adaptive approach suited to the specific ongoing event.

ACKNOWLEDGMENT

This work has been funded by the European Commission H2020 project E^{2}mC "Evolution of Emergency Copernicus services". Grant Agreement No. 730082. This work expresses the opinions of the authors and not necessarily those of the European Commission. The European Commission is not liable for any use that may be made of the information contained in this work.

REFERENCES

Alam, F., Ofli, F., and Imran, M. (2018). "Processing Social Media Images by Combining Human and Machine Computing during Crises". In: *International Journal of Human–Computer Interaction* 34.4, pp. 311–327.

Chen, T., Lu, D., Kan, M.-Y., and Cui, P. (2013). "Understanding and classifying image tweets". In: *Proceedings of the 21st ACM International Conference on Multimedia*. ACM, pp. 781–784.

Fohringer, J., Dransch, D., Kreibich, H., and Schröter, K. (2015). "Social media as an information source for rapid flood inundation mapping". In: *Natural Hazards and Earth System Sciences* 15.12, pp. 2725–2738.

Francalanci, C., Pernici, B., and Scalia, G. (2017). "Exploratory Spatio-Temporal Queries in Evolving Information". In: *Mobility Analytics for Spatio-Temporal and Social Data - First International Workshop, MATES 2017, Munich, Germany, September 1, 2017, Revised Selected Papers*, pp. 138–156.

Goldstein, J. and Rotich, J. (2008). "Digitally networked technology in Kenya's 2007–2008 post-election crisis". In: *Berkman Center Research Publication* 9, pp. 1–10.

Gupta, A., Lamba, H., Kumaraguru, P., and Joshi, A. (2013). "Faking Sandy: characterizing and identifying fake images on Twitter during hurricane sandy". In: *Proceedings of the 22nd international conference on World Wide Web*. ACM, pp. 729–736.

Havas, C., Resch, B., Francalanci, C., Pernici, B., Scalia, G., Fernandez-Marquez, J. L., Achte, T. V., Zeug, G., Mondardini, M. R. (, Grandoni, D., et al. (2017). "E2mC: Improving Emergency Management Service Practice through Social Media and Crowdsourcing Analysis in Near Real Time". In: *Sensors* 17.12, 2766, pp. 1–32.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015). "Processing social media messages in mass emergency: A survey". In: *ACM Computing Surveys (CSUR)* 47.4, p. 67.

MacEachren, A. M., Jaiswal, A., Robinson, A. C., Pezanowski, S., Savelyev, A., Mitra, P., Zhang, X., and Blanford, J. (2011). "Senseplace2: Geotwitter analytics support for situational awareness". In: *Visual Analytics Science and Technology (VAST), 2011 IEEE Conference on*. IEEE, pp. 181–190.

Murthy, D., Gross, A., and McGarry, M. (2016). "Visual Social Media and Big Data. Interpreting Instagram Images Posted on Twitter". In: *Digital Culture & Society* 2.2, pp. 113–134.

Nozza, D., Ristagno, F., Palmonari, M., Fersini, E., Manchanda, P., and Messina, E. (2017). "TWINE: A real-time system for TWeet analysis via INformation Extraction". In: *Proceedings of the 15th Conference of the European Chapter of the Association for Computational Linguistics, EACL 2017, Valencia, Spain, April 3-7, 2017, Software Demonstrations*, pp. 25–28.

Peters, R. and Albuquerque, J. P. de (2015). "Investigating images as indicators for relevant social media messages in disaster management". In: *12th Proceedings of the International Conference on Information Systems for Crisis Response and Management, Krystiansand, Norway, May 24-27, 2015.*

Pezanowski, S., MacEachren, A. M., Savelyev, A., and Robinson, A. C. (2018). "SensePlace3: a geovisual framework to analyze place–time–attribute information in social media". In: *Cartography and Geographic Information Science* 45.5, pp. 420–437.

Purohit, H., Castillo, C., Imran, M., and Pandey, R. (2018). "Ranking of Social Media Alerts with Workload Bounds in Emergency Operation Centers". In: *2018 IEEE/WIC/ACM International Conference on Web Intelligence (WI)*. IEEE, pp. 206–213.

Simulating real-time Twitter data from historical datasets

Shane E. Halse
Pennsylvania State University, USA
Seh297@ist.psu.edu

Rob Grace
Pennsylvania State University, USA
Wrg123@ist.psu.edu

Jess Kropczynski
University of Cincinnati
Jess.Kropczynski@uc.edu

Andrea Tapia
Pennsylvania State University, USA
ATapia@ist.psu.edu

ABSTRACT

In this paper, we will discuss a system design for simulating social media data based on historical datasets. While many datasets containing data collected from social media during crisis have become publicly available, there is a lack of tools or systems can present this data on the same timeline as it was originally posted. Through the design and use of the tool discussed in this paper, we show how historical datasets can be used for algorithm testing, such as those used in machine learning, to improve the quality of the data. In addition, the use of simulated data also has its benefits in training scenarios, which would allow participants to see real, non-fabricated social media messages in the same temporal manner as found on a social media platform. Lastly, we will discuss the positive reception and future improvements suggested by 911 Public Service Answering Point (PSAP) professionals.

Keywords

Twitter, Simulation, Crisis Response, Social Media

INTRODUCTION

Does it work? This is a question asked by many software and application developers when designing and developing new tools. This question however becomes much more complex when examining tools and applications designed to work in real time. Furthermore, when the application is designed to be used to support critical decision making that could affect lives of others, it has to work. With this in mind the software development cycle can be broken up into the five stages of; requirements analysis, design, implementation, testing and evolution or iteration.

Unfortunately, the world of software development is one that seems boundless, with each application having different requirements and goals. In order to provide focus to our research, we have chosen the domain of crisis response. In particular, we investigate software development tools for crisis response that look at how to best gather, filter, and curate data produced by citizens such as that found on social media. With people turning to social media to both disseminate and gather information, there is an abundance of information. For example, if we take the social media platform Twitter, infamous Hurricane Sandy during 2012 in which over 20 million tweets were posted over a five-day period (Halse et al. 2016). Next, as crisis responders only require actionable information with a high degree of veracity, much work as looked at how to improve the quality of this data through tools applying advanced filtering and machine-learning algorithms (Halse et al. 2016)(Caragea et al. 2011).

Due the nature of crisis response, the implementation phase of the software development cycle can be a particularly challenging one. Previous work has shown the value of tools for social media analysis for crisis responders along with the desire to use such tools (Alexander 2014). However, it is not without difficulties associate with deployment in the crisis response domain (Jin, Liu, and Austin 2011). These include difficulties in increasing the workload of the responders, especially during a crisis, along with providing adequate training tools

that are based on actual, non-fabricated datasets similar to those that would be seen during and event.

The next two crucial steps in the software development cycle, is that of implementation and testing. It is within these steps that we face two primary challenges in developing tools for crisis response. The first is the unpredictability of certain crisis. Some slow onset crisis, such as hurricanes, floods, and fires, provide enough time for researchers and end users to deploy and monitor software application for data. However fast onset crisis, earthquakes, bombings, and other manmade crisis may require advanced techniques for detection and identification. Furthermore, fast onset crisis also require the users of applications to have active ongoing data collection and analysis. The second issue regarding development of crisis response application is that of the temporal nature of the data collected during a crisis. While many discoveries and tools have been created through the analysis of full datasets, they are difficult to test and improve within a real time environment.

It is these last two steps in the software development cycle, which this paper will address. This is done through presenting a simulation tool designed to allow testing of software used for gathering, filtering and analyzing social media data. We discuss the system architecture, features and the results of a small workshop with crisis response professionals. Additional avenues, such as training, in which a simulator can be implemented, are also discussed.

RELATED WORKS

Social media contains a vast amount of data, be it a community or people sharing information about every day, to large organizations attempting to disseminate time sensitive critical information to the public. This makes it an ideal candidate for data collection and analysis, especially during emergencies when traditional avenues of information gathering and sharing may not be available. It has also become an important tool to reach those impacted by a crisis event (Kavanaugh et al. 2012). While there can be an overabundance of information found within social media sites, many previous research studies have been able to parse out particular information related to a given event. For example, work has shown that through using given keywords and machine learning algorithms, earthquakes events and information can be detected through messages found on Twitter (Crooks et al. 2013)(Sakaki, Okazaki, and Matsuo 2013). Likewise, social media has also been used to capture data for fires, shootings, hurricanes and building collapses (Palen 2008).

Furthering this frameworks, tools have also been developed to allow dynamic detection and capturing of data during a crisis (Bruns and Liang 2012). With many frameworks and analysis methods available, tools have been developed for use by crisis responders. Some of these tools include; Earthquake and reporting system (EARS) (Avvenuti et al. 2014), Tweet4act (Chowdhury, Chowdhury, and Castillo 2013), SensePlace (MacEachren et al. 2011) and TweetTracker (Kumar et al. 2011). Unfortunately, despite the availability of these tools, social media remains a "white whale" for crisis responders. A solution to social media adoption by crisis responders can be addressed through examining two primary concerns; the first is identifying which of the tools are most effective and identifying areas in which they can be improved, with the second being developing simulated training environments for the top performers. This has been approached in previous work which investigated how data can be used to design, develop and improve tools the emergency responders (Hampton et al. 2017). However, this work utilizes data that is fabricated artificially. In this work, we utilize previously collected corpuses from real messages posted on Twitter.

With the first concern in mind, and with the use of simulations in crisis response shown to be an effective method by which to improve the quality of software applications and algorithms used in crisis response (Walker and Giddings 2011), we can begin to standardize the testing environments. Through standardizing the simulation inputs and outputs with the same datasets, we can reduce any additional confounding variable during testing. Previous research has shown that valuable information in system design can be gained, especially through incorporating user centered design (Kluckner and Wendt 2014). This is done through presenting end users with a simulated environment to determine what information they feel is most relevant. Likewise, through incorporating the results of studies into a simulated environment, software developers have an ability to compare one iteration and design to another based on user feedback. Standardizing the simulated environment also opens avenues in which policies and procedures can be created.

In addition to testing, and with respect to the second concern, standardizing simulation environments allows for the development of training protocols. Training for crisis responders with games and simulations has had much success in previous literature (Heldal and Wijkmark 2017) (Parush et al. 2016). These two examples describe how through simulations, training is both reduced in cost and increased in effectiveness. This combats the problem of users being unfamiliar with the system during times of crisis. It is through training that the user can develop a better understanding of the system and learn the limitation or advantages within (Schaefer et al. 2014). Additional works have also stressed the importance of training, especially when the system be utilized is novel and the user is unfamiliar with it (Abbasi and Kumar 2012)(Baumgart et al. 2006). Rather than having to wait for a particular event to occur in real time, simulations within a training environment provide the ability to control which data set and corresponding event is being used. In addition to this, with data collected during previous crisis, crisis

responders can identify particular keywords, search tactics and analysis strategies. This is particularly important when the data used for the simulation has been localized to their area of interest.

SIMULATOR SYSTEM DESIGN ARCHITECTURE

The goal of this simulator is not to create new social media messages, but instead is to take messages that have been collected from previous datasets. These messages would then be sent in the same temporal pattern as they were originally posted. Rather than send a fully collected dataset to a software application, the basic premise of this simulator is to read in the data one message at a time, detect the timestamp for that message and then send the data after a given amount of time has passed. That is, once the simulator has begun running it starts at a predetermined historical timestamp such as 1 hour before the event had occurred. It would then calculate the delay between this time and the timestamp found from the Twitter message. After the simulator had been running for this delay, it would then send that message. For example, if we set our simulators start time to 11:00, and had an event such as a shooting, where the first message about the shooting was posted at 11:57, then it would take 57 minutes for that message to be shown (assuming a timescale of 1:1). This emulates the temporal nature that would be seen from data gathered during a crisis event. Figure 1 below shows how the simulator is connected to existing tools with the minor addition of a data adapter.

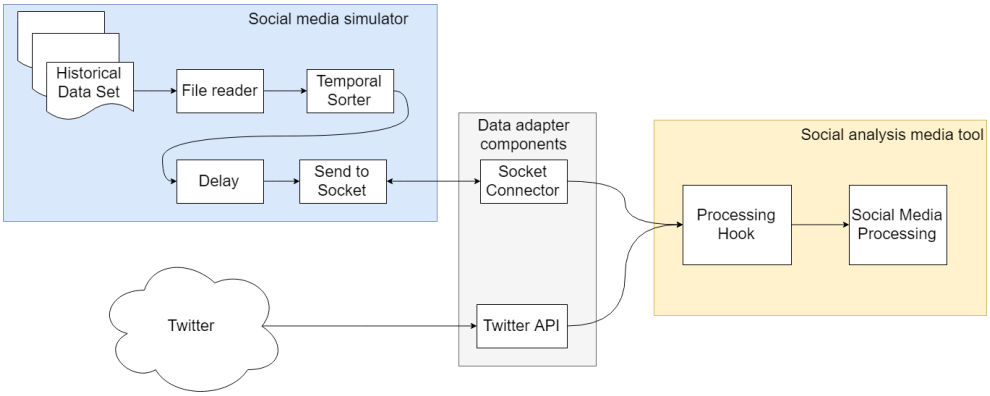


Figure 1 - Overview of system usage

From Figure 1 we can see that the social media simulator is implemented in place of collecting data directly from Twitter. The concept here is to allow developers to leverage previously collected datasets, that are crisis related, to test and improve their designs. The goal of the simulator is not to replace data collected from Twitter, however there is not always a crisis occurring that can be used for development purposes. It is through the adapter component that the source of the data would be selected. In the diagram above we have shown the adapter as a separate component however it can be easily incorporated into the existing social media analysis tools. This way the developers can choose if they would prefer live data, (assuming a crisis is ongoing) or simulated data based on a selected dataset.

Data

In order to create a tool that leverages historical datasets to produce a simulated social media stream, historical datasets are needed. The datasets used for testing in our case was those publicly available from crisislex.com and described in the works of (Olteanu et al. 2014). This collection contains data collected on over 30 different crisis events. As each data set has the potential to contain many different data points, we began by defining some of the fields that would be required to create a simulation stream. As the simulator's main purpose was to deliver tweets from these datasets in the same temporal nature to how they were originally found, the first required data point is that of a timestamp. Next, the simulator detects one of two possible conditions: data containing a messageID, and data with no messageID but does have message context. In some cases, the creators of a dataset did not collect additional information concerning a message, but instead only a timestamp and a messageID were collected. If no messageID is available then only the message content data field is used. While it is possible for the datasets to contain additional informational fields, our simulator is primarily concerned with displaying each of the tweet's message in the same temporal order originally seen. Each of the data points are explained in more detail in the following sections.

Timestamp (Required)

The timestamp for the data is required as this serves as the basis for when to send or show the data. This tool looks for the timestamp with the earliest value and uses this as the simulators start time (startTimestamp). It then

calculates the value (in milliseconds) between the earliest timestamp and the next timestamp (nextTimestamp). This is done using the following formula deltaTime = nextTimestamp – startTimestamp. One the value for how much time exists between the start time and corresponding tweet's timestamp (deltaTime) has been calculated, a delay of deltaTime is implemented before displaying the message data. For example to increase the speed at which messages are displayed we can divide deltaTime by the scale factor. The pseudo code snippet looks like this:

```
Loop for each message in dataset
deltaTime =   nextTimestamp – startTimestamp;
        timePassed = nowTime – codeExecutionStartTime;
        if(timePassed > deltaTime/timeScaleFactor)
                Show/Send message
endLoop
```

It is important to note that while the simulator is designed to present messages found in a dataset at the same speed they were originally displayed, a timeScaleFactor was added to allow for accelerated testing. For example, if we wanted to test the performance of an analysis algorithm in pseudo realtime, a time scale factor could be used as some of the datasets were collected over a period of many days. However, if the timescale is changed it is important to adjust the parameters of any tools that expect data in real time. Furthermore, by using a timeScaleFactor variable, we provide two features of the simulator. The first is to allow computational tools to be tested at an accelerated rate, whereas the second feature offered is the ability to provide end user the ability to slow or speed up the data. In training scenarios it may be necessary to pause or slow the data stream down to allow for explanation and topics to be discussed.

MessageID (Required if no message content)

Some datasets do not contain information beyond a timestamp and a messageID. This is particularly true with Twitter datasets that require a process knowns rehydration. Rehydration occurs when only as some situations Twitter do not allow the message contents of a tweet to be shared but instead only allows the sharing of the tweet's timestamp and its tweet ID. In these cases, the simulator connects to the Twitter API and requests information for the given messageID. If the contents of a message are not available, the simulation tool connects to the Twitter API to retrieve the relevant message data. As such, the message ID for each message within a data set is required if there is no corresponding content. In addition, with messageIDs other Meta data can be collected for further analysis such as number of retweets, likes, media links and poster's information.

Message content (Optional)

Message content is a field found in some of the datasets and is essentially the body or message of a tweet that contains only the text portion of a Twitter message. The simulator is designed to use this message field if it is found in the corresponding dataset. As the primary interest of the researchers in this paper was to present message content to a separate analysis tool, this field was used when found. If however the dataset did not contain the contents of messages, the rehydrating process described above was used.

Other Information (Optional)

As mentioned previously the datasets that we used for testing the Twitter simulator contained many different data fields. With this in mind, we limited the required fields to only that of a timestamp and a MessageID. However, additional fields such as coding fields for each tweet can easily be added. This in turn would then be added to the output to be used later by other applications.

Input data

Due to the similarity of the datasets used during testing, a comma separated (.csv) file structure was used for the input file. This is not however a limitation but rather a design choice as most of our test datasets were contained within the csv files. In a similar manner, any delimited file could be used as the input to the simulator with minor modification. Furthermore, while not implemented in the current vision of the simulator, additional data input formats could be added in the future such as database connections or JSON and XML formats.

Data handling

The simulator is responsible for parsing data from a given input file, selecting the appropriate fields, analyzing the time sequence of tweets, creating a connection endpoint and outputting the data to that connection endpoint. The code for the simulator was written in Java. As we are using .csv dataset file the first step of the simulator is to read each file in. it then parses out fields such as timestamps, messageID, message content and any additional fields contained. Furthermore, if additional information is required, the simulator would query the Twitter API using the messageID as a reference to request information about the respective message. After this, a time sequence is calculated using the earliest tweet as a reference, delays are calculated using the formula described in

the Timpstamp section. After the delay has occurred (amount of time between first tweet's timestamp and current timestamp) the data from a particular tweet is converted into a JSON format and sent to the endpoint. Any tools connected to that endpoint would then be responsible for processing the data.

Output data

The output data is sent via a connected socket. The simulator begins by opening a listening port and then sends the processed data to any applications connected to that socket for the given tweet's timeline. The format of the output of the simulator uses Javascript Object Notation (JSON). This entails that any application wishing to leverage the simulator should be capable of handling this format. However, this format could be replaced or additional formats added in future releases.

TWITTER SIMULATOR USE CASE

In order to test the effectiveness of our Twitter simulator we deployed a simple prototype in an active 911 public service answering point (PSAP). This center was located in a city with a population over 100,000 people. The first visit took place in May of 2018, with the primary goal on initial discovery. That is, during this visit we were interested in gaining a better understanding of how 911 centers operate and if social media could provide value to the existing processes. The primary goals of the first visit was to conduct observational research, interviews and workshops in order to discover what tasks and procedures were used. In addition, we also investigated how social media is currently used, and the possible future avenues of its use within the 911 environment. Lastly, challenges involving communicating data obtain from social media and potential other sources were discussed. These interviews shed light on how the data from social media should be displayed and presented for use by the center. It also helped us understand the importance of specific pieces of information, in particular the following categories emerged: what was the location or "where" was the person making the tweet, what was the timeline of the incident or "when" did it occur, "who" was involved in the incident, "what" was the nature of the incident, where there "weapons" or use of weapons mentioned and "why" had the incident occurred. These information points were referred to as the 6w's.

We then conducted an in person, informal workshop. This involved simulating data using the 2013 airport shootings in Los Angeles USA dataset found in the CrisisLexT26 dataset from crisislex.org (Olteanu, Vieweg, and Castillo n.d.). As the airport shooting occurred at 9:24 am only the hours of 8am – 12pm were used. A timescale of 15 was used meaning that the total simulation took 16 minutes. The first reference to LAX and shooting did not occur until the fifth minute of the simulation. This was used across three different participant groups. In addition to monitoring and examining how the prototype was used, we also observed the interaction between the participants to determine how the data from social media may be integrated into the existing process and if any disruptions had occurred.

In order to mimic the PSAP's existing procedures, sets of three participants were used, one as a traditional call taker, one as a social media analysist and one as a dispatcher. Each of these participants were 911 professionals working in the call center with multiple years' experience. All participants had access to the social media prototype interface user interface.

The social media prototype GUI was built on the ELK stack. The ELK stack is an open source software platform consisting of three primary components (https://www.elastic.co/). The first is a mechanism to import data from one format into another. In our case this was the role of the simulator tool, which imported data from the T26 LAX shooting dataset into the stack. The second mechanism is the elastic search analytics engine, which performs similar to a database. The third component was Kibana which is a user interface designed to display information from the elastic search environment. This allows you to create custom dashboards and interfaces. An example of this interface can be seen in Figure 2.

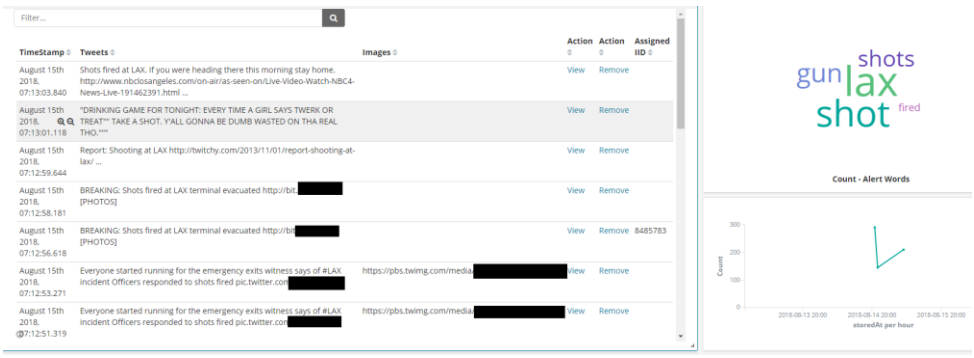


Figure 2 - Example Interface

Figure 2 illustrates a simple user interface developed using Kibana. While there is much room for improvement the goal of this work was to develop a tool capable of simulating Twitter data collection in real time. From the figure we have three primary data points displayed. The first is a table containing a list of tweets (which updates in real time) along with the associate timestamps, and image links. The other columns, action (view), action (remove) and assign incident id (iid) were used in conjunction with our prototype. The first action (view) allows the user to view the details of the tweet with second action (remove) allowing the user to remove a particular tweet from the database (Elasticsearch). Lastly, assigned IID allowed users to connect a tweet to a particular incident within their system. The assig IID was for display purposes only.

Overall, the participants were impressed with the ability to present previous data in a real-time format. Unfortunately, they did say that there was too much data being presented to fast. It was then explained that the data they were seeing was at an accelerated rate. Two recommendations to combat this issue were discussed and presented. The first was to narrow down the data further to show 10-15 minutes before the incident and 30-40 minutes after that. This was suggested, as they (crisis responders) would only really be interested in the event onset and possibly any victims. Once the suspect had been apprehended, further data would not necessarily be required. While we only used the airport shooting data during our workshop it is highly suggested that further work is done to test slow onset crisis such as floods, and hurricanes.

The second recommendation was to filter out more noise and allow for custom searches. As the tweets shown to the users were based on the dataset, no further filtering was implemented. Note that the datasets were collected using various keywords and collection methods originally. While this could be a side effect of the rate at which the tweets were been shown, allowing custom filtering to be setup within the simulator would allow users to fine tune the data that is shown during training exercises.

The last recommendation was to use a localized dataset. While the LAX dataset did have some clear useful information in it, those who were unfamiliar with the lingo of area may not be able to identify points of interest. This was found to be especially true when images were presented, as the PSAP was not located in the LAX area, they were unable to identify where the picture may have been taken. Additional examples of images were presented in another session to which the crisis responders were quickly able to identify where the picture was taken.

CONCLUSION

Previous research done on datasets has mostly looked at datasets as a whole in identifying patterns within the messages. These patterns are then used in the design of new methods for data collection and analysis. While this technique has been somewhat successful, two primary issues still exist. The first is that when messages are collected in real-time access to the overall picture, or the full dataset, is not available until after the event has occurred. The developers of these tools must then examined how each of them performed iterate the design and then wait for another event to occur to test the changes. Secondly, with respect to training, Twitter contains a vast amount of information, with many unique ways of sharing information. Unfortunately, developing a tool that attempts to create these messages for training purposes becomes less than ideal as different areas or languages may report things in different ways. Lastly, by involving the 911 operators in the design the prototype we can discover key data points and information that they would use within the existing process.

In order to address these issues, this paper describes the design and creation of a tool to present and simulate Twitter message from previously collected datasets. By doing this, the first issues is combatted the tweets are presented based on their timestamp meaning that tools connected to the simulator would not be able to analyze the full dataset at once and instead only receive data up to a given time point with new data flowing in as time progresses. This temporal delivery can also serve as a method for testing a systems robustness and assist in discovering the limits or requirements of an analysis application. A Twitter simulator can also assist as an input to existing training tools. Because we are leveraging existing datasets, actual tweet messages are used. This means that the issues of tweet fabrication can be overcome as the tweets are written by humans and not auto generated.

In being able to test this simulator with actual crisis response professionals, we gained valuable insight into the design. The following design recommendation were discovered

- If training or humans are being used to analyze data, a timescale for accelerated tweet delivery should be used very cautiously
- The timescale feature should be used only for computational analysis and tool testing
- Crisis response professionals would only need to see a very time limited margin of tweets to assess the value of the data depending on the dataset
- Consider incorporating custom filtering into the simulator for training purposes
- When at all possible use localized datasets

The design and development of this Twitter simulator is still ongoing, with many features to be added in the future. First with respect to the data input, this system would benefit from the ability to connect to databases as

well as accept input files in different formats besides the .csv datasets used. Likewise, datasets from social media platforms other than Twitter would need to be incorporated into the design depending on the availability of their APIs. Next, while intentionally left out of our design, incorporating filter methods could also be added for those wishing to use the simulator without needing to connect it to an existing application. Lastly, while we selected the JSON format as our output due to familiarity, additional output formats would be needed including; database connection, REST calls and raw file outputs.

REFERENCES

Abbasi, Ma, and Shamanth Kumar. 2012. "Lessons Learned in Using Social Media for Disaster Relief-ASU Crisis Response Game." *Social Computing, ...*: 282–89. http://link.springer.com/chapter/10.1007/978-3-642-29047-3_34.

Alexander, David E. 2014. "Social Media in Disaster Risk Reduction and Crisis Management." *Science and Engineering Ethics* 20(3): 717–33.

Avvenuti, Marco et al. 2014. "EARS (Earthquake Alert and Report System): A Real Time Decision Support System for Earthquake Crisis Management." *Proceedings of the 20th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*: 1749–58. http://doi.acm.org/10.1145/2623330.2623358.

Baumgart, Leigh A, Ellen J Bass, Brenda Philips, and Kevin Kloesel. 2006. "Emergency Management Decision-Making during Severe Weather." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50(3): 381–85. http://pro.sagepub.com/cgi/content/abstract/50/3/381.

Bruns, Axel, and Yuxian Eugene Liang. 2012. "Tools and Methods for Capturing Twitter Data during Natural Disasters." *First Monday* 17(4): 1–17.

Caragea, Cornelia et al. 2011. "Classifying Text Messages for the Haiti Earthquake." *Proceedings of the 8th International ISCRAM Conference* (May): 1–10.

Chowdhury, Roy, Soudip Roy Chowdhury, and Carlos Castillo. 2013. "Tweet4act : Using Incident-Specific Profiles for Classifying Crisis-Related Messages." *Proceedings of the 10th International ISCRAM Conference* (May): 834–39.

Crooks, Andrew, Arie Croitoru, Anthony Stefanidis, and Jacek Radzikowski. 2013. "#Earthquake: Twitter as a Distributed Sensor System." *Transactions in GIS* 17(1): 124–47.

Halse, Shane E., Andrea H. Tapia, Anna C. Squicciarini, and C Caragea. 2016. "An Emotional Step Towards Automated Trust Detection in Crisis Social Media." *ISCRAM 2016 proceedings*.

Hampton, Andrew J et al. 2017. "Constructing Synthetic Social Media Stimuli for an Emergency Preparedness Functional Exercise."

Heldal, Ilona, and Cecilia Hammar Wijkmark. 2017. "Simulations and Serious Games for Firefighter Training : Users ' Perspective." (May): 868–78.

Jin, Y., B. F. Liu, and L. L. Austin. 2011. "Examining the Role of Social Media in Effective Crisis Management: The Effects of Crisis Origin, Information Form, and Source on Publics' Crisis Responses." *Communication Research* 41(1): 74–94. http://crx.sagepub.com/content/41/1/74.abstract.

Kavanaugh, Andrea L et al. 2012. "Social Media Use by Government : From the Routine to the Critical." *Government Information Quarterly* 29(4): 480–91. http://dx.doi.org/10.1016/j.giq.2012.06.002.

Kluckner, Sigmund, and Willi Wendt. 2014. "Designing for the User : Tailoring a Simulation Software Interface to the Needs of Crisis Managers." (May): 528–32.

Kumar, Shamanth, Geoffrey Barbier, Mohammad Ali Ali Abbasi, and Huan Liu. 2011. "TweetTracker: An Analysis Tool for Humanitarian and Disaster Relief." *Fifth International AAAI Conference on Weblogs and Social Media*: 661–62.

MacEachren, Alan M. et al. 2011. "SensePlace2: GeoTwitter Analytics Support for Situational Awareness." *VAST 2011 - IEEE Conference on Visual Analytics Science and Technology 2011, Proceedings*: 181–90.

Olteanu, Alexandra, Carlos Castillo, Fernando Diaz, and Sarah Vieweg. 2014. "CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises." *Proc. of the 8th International Conference on Weblogs and Social Media*: 376. http://www.aaai.org/ocs/index.php/ICWSM/ICWSM14/paper/download/8091/8138.

Olteanu, Alexandra, Sarah Vieweg, and Carlos Castillo. "What to Expect When the Unexpected Happens : Social

Media Communications Across Crises."

Palen, Leysia. 2008. "Online Social Media in Crisis Events." (3): 76–78.

Parush, Avi, Ruth Libkind, Shani Laendler, and Tal Solomon. 2016. "Simulator and Game-Based Multi-Level Training of Cognitive Skills and EMS Teamwork in Multi-Casualty Incident Management." (May 2016): 2016.

Sakaki, Takeshi, Makoto Okazaki, and Yutaka Matsuo. 2013. "Tweet Analysis for Real-Time Event Detection and Earthquake Reporting System Development." 25(4): 919–31.

Schaefer, K. E. et al. 2014. "A-Meta-Analysis-of-Factors-Influencing-the-Development-of-Trust-in-Automation-Implications-for-Human-Robot-Interaction.Pdf." *Human factors* 58(3): 377.

Walker, Warren E, and Jordan Giddings. 2011. "Training and Learning for Crisis Management Using a Virtual Simulation / Gaming Environment." : 163–73.

Sympathy Detection in Disaster Twitter Data

Yingjie Li
University of Illinois at Chicago
yli300@uic.edu

Seoyeon Park
University of Illinois at Chicago
spark313@uic.edu

Cornelia Caragea
University of Illinois at Chicago
cornelia@uic.edu

Doina Caragea
Kansas State University
dcaragea@ksu.edu

Andrea Tapia
Pennsylvania State University
atapia@ist.psu.edu

ABSTRACT

Nowadays, micro-blogging sites such as Twitter have become powerful tools for communicating with others in various situations. Especially in disaster events, these sites can be the best platforms for seeking or providing social support, of which informational support and emotional support are the most important types. Sympathy, a sub-type of emotional support, is an expression of one's compassion or sorrow for a difficult situation that another person is facing. Providing sympathy to people affected by a disaster can help change people's emotional states from negative to positive emotions, and hence, help them feel better. Moreover, detecting sympathy contents in Twitter can potentially be used for finding candidate donors since the emotion "sympathy" is closely related to people who may be willing to donate. Thus, in this paper, as a starting point, we focus on detecting sympathy-related tweets. We address this task using Convolutional Neural Networks (CNNs) with refined word embeddings. Specifically, we propose a refined word embedding technique in terms of various pre-trained word vector models and show great performance of CNNs that use these refined embeddings in the sympathy tweet classification task. We also report experimental results showing that the CNNs with the refined word embeddings outperform not only traditional machine learning techniques, such as Naïve Bayes, Support Vector Machines and AdaBoost with conventional feature sets as bags of words, but also Long Short-Term Memory Networks.

Keywords

Refined Word Embedding, Deep Learning, Machine Learning, Sympathy Tweets Detection

INTRODUCTION

Sympathy is an expression of one's compassion or sorrow for a difficult situation that another person is facing. Expressing sympathy for people who are facing disaster situations is one way of caring for people emotionally. S. Kim et al. (2012) discovered that the expression of certain emotions, including sympathy "influences" other people in Twitter to become more positive. Moreover, Froyum (2018) discussed that if an emotional connection between helper and helped exists, e.g., sympathy, helpers are more eager to give assistance in various kinds of formats. According to Baberini et al. (2015), there is a higher chance that people who express sympathy could potentially provide monetary helping hands since they are emotionally inclined to people who are encountering disasters status. Donations are very important to people in crisis circumstances for restoring their lives.

Since micro-blogging social media sites such as Twitter are widely used nowadays, people get real-time information by using these sites. Not only limited to personal use for acquiring knowledge, exploiting social media as information sources in groups has shed light on earning valuable resources. For example, for building "post-disaster" programs,

Table 1. Examples of Sympathy Tweets and Non Sympathy Tweets

Sympathy Tweets	Non Sympathy Tweets
RT@HotelElGanzo: We send our best wishes and thoughts out to everyone who is being affected by #HurricaneODILE - Please stay safe #Cuidense	RT @RedCross: To check on loved ones in #Baja impacted by #Odile, contact State Departments Overseas Citizen Services at 1-888-407-4747
#India deepest sympathy and respect to all those killed or injured in the flood	Floods triggered by heavy rainfall in Himalayas wreak havoc in North India, inundates 1500 villages in Uttar Pradesh http://t.co/W97qixmYQ5
Hoping for best: Powerful earthquake shakes Northern California http://t.co/gvBVrSbLgN http://t.co/aCgUeEt8ZE	#news U.S. quake: The recovery from the strongest earthquake in 25 years to strike Northern California will be... http://t.co/OxVb2dGtWj

non-profit organizations can use Twitter as information roots. More specifically, in emergency situations like earthquakes, floods and typhoons strike, Red Cross can use Twitter as a source of big-data analysis for figuring out long-term donors. According to Han et al. (2013), identifying long-term donors is crucial because they need to plan longstanding programs such as fund-raising campaigns. However, Han et al. (2013) reported the fact that when a disaster happens, one-time donations usually spike sharply. Twitter, which is a real-time posting platform, can be a good resource for extracting valuable information since we can easily notice this sharply increasing one-time donation phenomenon in real-time.

Thus, our goal in this paper is to identify Twitter postings (or tweets) that have sympathy related contents. This can be used not only for designing improved features in Twitter for providing emotional support, but can also be used for identifying users that can be candidate donors. Consequently, we learn supervised models to automatically detect sympathy in Twitter data. Our labeled Twitter data comes from a series of diverse disasters that happened during 2013 to 2015 world-wide. Examples of tweets that contain and do not contain sympathy are shown in Table 1.

Many natural language processing approaches for short text or sentence classification use Convolutional Neural Networks (CNNs) (Y. Kim 2014) and Long Short-Term Memory Neural Networks (LSTMs) to reduce the burden of feature engineering. In text processing, deep learning approaches are predominant in terms of feature detection since humans do not need to intervene in a detailed way. Deep learning approaches have achieved substantial success over traditional machine learning techniques in disaster contexts as well (V. K. Neppalli et al. 2018; Nguyen et al. 2017; C. Caragea, Silvescu, et al. 2016; Ben Lazreg et al. 2016). For example, Nguyen et al. (2017) used CNNs to classify tweets into categories related to situational awareness and showed improvements over traditional algorithms. Ben Lazreg et al. (2016) used a different deep learning approach, specifically a Long Short-Term Memory (LSTM) network, to learn a model from crisis tweets and used this model to generate snippets of information summarizing the tweets. In addition to these, V. K. Neppalli et al. (2018) reported that CNNs outperform Naïve Bayes that exploit Twitter specific features and conventional linguistic features in Twitter informative posting classification.

In this paper, we focus on sympathy detection of Twitter disaster data using Convolutional Neural Networks. Conventional word embeddings such as pre-trained word2vec, Glove, FastText, and a domain-specific word2vec trained on CrisisNLP data (Imran, Mitra, et al. 2016) are used to test the performance of our proposed model. We observe that even if two different words look similar or are semantically related, conventional word embeddings based model may not consider them as tightly correlated, and hence, return a low similarity value. For example, when we use the CrisisNLP word embeddings for measuring the similarity of words "pray" and "prayer", the similarity value that implies how much they are alike is significantly low. In order to mitigate this problem, we design a refined word embedding technique based on word stemming, where semantically similar words become closer in the vector space. Our technique is inspired from Yu et al. (2017) who used a sentiment lexicon for generating polished word embeddings. By using refined word embeddings, we achieve an F1 score of approximately 76% as compared with approximately 74% achieved by conventional word embeddings. In experiments, we also contrast CNNs with two other deep learning models, LSTM and Bi-LSTM. In summary, our contribution can be organized as follows:

- We explore CNNs with various word embeddings (pre-trained and fine-tuned on domain specific data) for sympathy detection of Twitter disaster data. Moreover, we design a word stemming based refinement model to improve word representations in vector space.

- We show that the CNNs with refined word embeddings outperform the CNNs with conventional word embeddings. In addition, we contrast the CNNs with LSTMs and Bi-LSTMs and show that the CNNs (with and without refined word embeddings) have better performance in most cases.
- Our CNN models outperform traditional approaches such as decision tree and SVM on sympathy detection task. The F1 score of proposed model is 3.63% higher than SVM, which has the best performance in traditional classifiers.

RELATED WORK

Substantial progress has been made in extracting, processing and classifying messages posted in social media during disaster events, using natural language processing and machine learning techniques (C. Caragea, Squicciarini, et al. 2014; Verma et al. 2011, Sarda and Lal Chouhan 2017, Rudra, Sharma, et al. 2018). For example, Ashktorab et al. (2014) used a combination of classification, clustering, and extraction methods to identify actionable information for disaster responders. Imran, Elbassuoni, et al. (2013) classified tweets into situational awareness categories, such as caution and advice, casualties and damage, donations, people missing, using unigrams, bigrams, POS tags, presence of URL/hashtags, tweet length, etc. Yin et al. (2012) used similar features to identify tweets related to a disaster, identify disaster type and assess the impact of a disaster. Rudra, Ghosh, et al. (2015) used lexical features to extract situational information in disasters. More recently, researchers started to explore deep learning techniques, and in particular Convolutional Neural Networks and word embeddings, for classifying disaster social media data into diverse categories such as situational awareness, informational tweets, and actionable tweets (Alam et al. 2018; Derczynski et al. 2018; V. K. Neppalli et al. 2018; Nguyen et al. 2017; C. Caragea, Silvescu, et al. 2016).

Sentiment analysis and emotion detection have also been explored in disaster contexts. For example, Nagy and Stamberger (2012) focused on sentiment detection in Twitter during the San Bruno, California gas explosion and fires from 09/2010. They used SentiWordNet together with dictionaries of emoticons and out of vocabulary words, and a sentiment-based dictionary to identify the basic sentiment of a tweet. Schulz et al. (2013) focused on the classification of human emotions into six classes: anger, disgust, fear, happiness, sadness, and surprise, from tweets related to the Hurricane Sandy. As features, they used bag of words, part of speech tags, character n-grams (for n=3,4), emoticons, and sentiment-based words compiled from the AFINN word list (Nielsen 2011) and SentiWordNet (Baccianella et al. 2010). Mandel et al. (2013) performed a demographic sentiment analysis using Twitter data during Hurricane Irene. K. Neppalli et al. (2017) explored the concept of *emotional divergence* and analyzed how likely a tweet is to be retweeted with respect to its emotional divergence value, using Twitter data from the Sandy Hurricane. *Emotional divergence*, first introduced by (Pfitzner et al. 2012), measures the diversity of the emotions expressed in a text.

Social support is one important aspect for which people join social networks, and hence, researchers investigated the types of social support (e.g., emotional support and informational support) and their benefits in these networks. For example, Bautista and Lin (2015) studied social support in tweets posted during a terrorist manhunt in Philippine, in which 44 elite policemen died, and found that informational support was more frequent compared with emotional support. Among the sub-types of informational support, the authors found that a large fraction of the posted tweets contained news-related pictures and articles. Similarly, during the Great East Japan Earthquake of March 2011, the city lost electricity and water and communication became inaccessible. Smartphone became the primary device to obtain information and communicate with each other. The author found that Twitter has the potential to disseminate important information, which is greatly beneficial during the disaster (Kaigo 2012). When the massive floods happened in Queensland, Australia, during December 2010 to January 2011, the social media platforms provided valuable information to the public. Not only for this, social media was also used as communication channels to people who were facing emergency disaster situations (Bunce et al. 2012). Emotional support in Twitter shows benefits on people's moods and behavior. Generally, when people feel emotionally supported, they tend to feel better. For example, in a study on social aspects of emotions in the general Twitter, S. Kim et al. (2012) showed that the expression of certain emotions, including *sympathy*, "influences" others to become more positive. More precisely, the authors discovered that changes in emotional states from negative to positive are influenced by topics such as greeting, sympathy and recommendation, whereas changes from positive to negative are influenced by topics such as worry, teasing, and complaint (S. Kim et al. 2012).

Against this background, we explore and contrast deep learning models, Convolutional Neural Networks (CNNs) and Long Short-Term Memory Networks (LSTMs), and refined word embeddings for *sympathy detection* in disaster-related Twitter data. Imran, Mitra, et al. (2016) presented results on a multi-class classification task for classifying disaster-related tweets into situational awareness categories of which sympathy and emotional support represents one such category. However, unlike Imran, Mitra, et al. (2016), we present a thorough analysis of sympathy detection and propose a word embedding technique that produces more suitable embeddings for our task.

METHODS

Nowadays, CNNs perform well on many text classification tasks. For example, Y. Kim (2014) showed that a CNN with a convolution and pooling layer can produce good performance on several classification tasks including sentiment analysis and question classification. Zhang and Wallace (2017) conducted extensive experiments of CNNs on sentence classification task. The authors concluded several useful suggestions that are helpful for applying CNNs to sentence classification. Aipe et al. (2018) developed a CNN model for multi-label classification of disaster dataset. Specific linguistic features are extracted from tweets to augment the original CNN model.

Based on these previous works, we use a CNN model for the classification of tweets as containing sympathy or not. Figure 1 shows our proposed architecture which is inpired from Y. Kim (2014) and Aipe et al. (2018). The CNN models generally work better when the input is given as word embeddings.

Word embeddings are trained from a very large corpus to generate effective representations for words with similar meanings. This method contributes to the progress of word representations and thus has been widely used in text classification and machine translation areas. Nowadays, it is very convenient for people to apply pre-trained word embeddings(e.g., GoogleNews and Glove) to their applications and get satisfying results. In our paper, we mainly discuss four word embeddings: CrisisNLP, GoogleNews, Glove and Fasttext. Different from the others, CrisisNLP is a word2vec embedding trained in a smaller dataset, which can be regarded as domain embedding.

A common problem existent in current word embeddings is that semantic consistency is hard to maintain in vector space, which means the most similar words of a target word in word space are irrelevant to the target word in some cases. And meanwhile, the synonyms of target word are far from the location of target word in the vector space. This problem is clearly illustrated in Figure 2a. The red numbers in this figure are cosine similarities between the target word and its synonyms and all other words are top 20 most similar words of target word 'pray'. Target word 'prays' is far from its synonyms and thus has low cosine similarities with those words. Therefore, it restricts potential improvement of some fine-tuned classifiers.

In order to address similar problems in sentiment analysis, Yu et al. (2017) proposed a refinement model to converge sentimentally similar words by using sentiment lexicon. The results show that it has good performance in both binary and fine-grained sentiment classification tasks. However, this model is only designed to improve the sentiment embedding or conventional embedding applied in sentiment analysis. Therefore, inspired by this model, a more general refinement method of conventional word embedding is proposed in this section. The procedure for refining word embeddings can be divided into three stages. First, Snowball stemmer is used to cluster words with similar meanings, which means that words with same stem are regarded as one cluster. Second, words in each cluster move close to each other in the vector space to get better representations, following the approach described below. Finally, the refined embedding is fed as the input of CNN model and yields better performance in sympathy detection task. As we can see in Figure 2b, the synonyms of the target word move much closer to the target word in the vector space with refinement model, which brings better word representations in sympathy detection.

Snowball stemmer is by far the most popular stemmer and performs better when compared with original Porter stemmer. The comparison between original Porter stemmer and Snowball stemmer is shown in Table 2. We can clearly observe that Snowball stemmer is more precise than Porter stemmer. For all selected vocabulary words in conventional word embedding, we have over 40,000 clusters in total after running Snowball stemmer and these clusters are used to improve the word representations in vector space. After we obtain the word clusters for original

Table 2. Porter stemmer vs. Snowball stemmer

Stemmer	Word cluster
Porter stemmer 'gener'	'general', 'generation', 'generator', 'generous', 'generations', 'generate', 'generally', 'generated', 'generals', 'generic', 'generously', 'generators', 'generating', 'generates', 'gener', 'generational', 'generalize', 'generalizing', 'genere', 'generalizations', 'generalization', 'generalized', 'generics', 'generative', 'generalities', 'generou', 'generality', 'generically'
Snowball stemmer 'generat'	'generation', 'generator', 'generations', 'generate', 'generated', 'generators','generating', 'generates', 'generational', 'generat', 'generative'

word embedding, we'd like words in each cluster to move closer to each other in vector space and meanwhile not too far from their original locations. An objective function is presented to minimize the total distance among each cluster, which is defined as

$$\Phi(V) = \sum_{i=1}^{n} \sum_{j=1}^{k} w_{ij} dist(v_i, v_j) \quad (1)$$

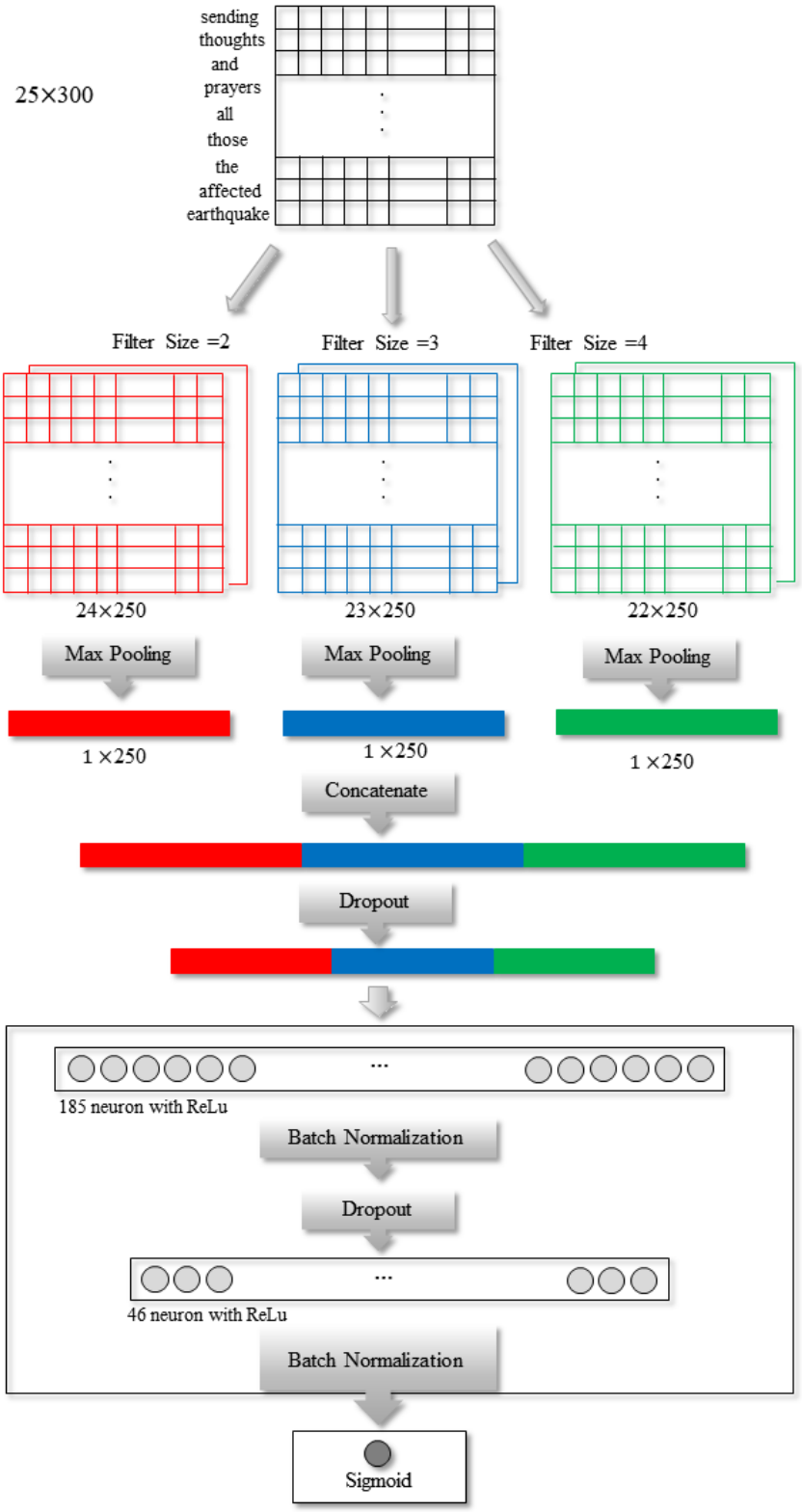
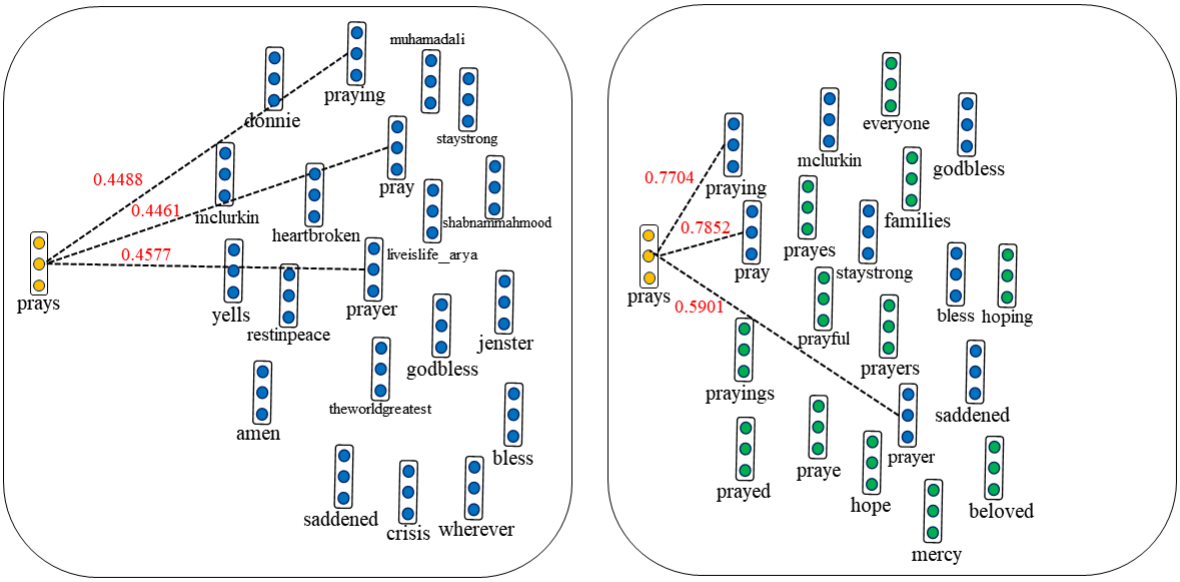


Figure 1. CNN Model



(a) Word embedding without refinement model

(b) Word embedding with refinement model

Figure 2. Conceptual diagram of word space for CrisisNLP embedding

where n denotes total number of clusters and k denotes the size of each cluster, dist(v_i,v_j) denotes the distance between target word v_i and similar word v_j, w_{ij} denotes the weight of each similar word related to target word. Each target word v_i has k-1 similar words within one cluster and the number of k may vary due to different size of clusters. Square Euclidean distance is used to calculate the distance between the target word and its similar words, defined as

$$dist(v_i, v_j) = \sum_{d=1}^{D} (v_i^d - v_j^d)^2 \tag{2}$$

where D is the dimension of pre-trained word embedding and w_{ij} is defined below

$$w_{ij} = \frac{1}{order_j} \tag{3}$$

where $order_j$ denotes the order of word in each cluster. Once we finish the word stemming, we have a fixed order for words in each cluster. In order to avoid putting weights on specific word in cluster, we randomly shuffle the order of each cluster when we run refinement model. To prevent refined model from destroying good word representations, a constraint, which is defined as the first part of objective function, is added to make sure the target word can only move with small steps in vector space. The objective function is defined as

$$argmin\Phi(V) = argmin \sum_{i=1}^{n} \left[\alpha dist(v_i^{t+1}, v_i^t) + \beta \sum_{j=1}^{k} w_{ij} dist(v_i^{t+1}, v_j^t) \right] \tag{4}$$

where v_i^{t+1} denotes word vector of target word in t+1 step, parameter α and β determine how far the target word can move away from its original location in vector space. To minimize the objective function, we set $\frac{\partial \Phi(V)}{\partial v_i^{t+1}}$=0 and target word vector is updated by

$$v_i^{t+1} = \frac{\alpha v_i^t + \beta \sum_{j=1}^{k} w_{ij} v_j^t}{\alpha + \beta \sum_{j=1}^{k} w_{ij}} \tag{5}$$

We need to tune three parameters: the number of iterations, α and β. The number of iterations controls the degree to which words converge in the vector space. α and β determine how far the target word can move for each iteration. In our experiments, iteration number=1, α=10 and β=1.

Table 3. # of Tweets for each label in CrisisNLP Data

Class	Train(70%)	Val(20%)	Test(10%)	# of Tweets
Sympathy and Emotional Support	1,378	394	197	1,969
Caution and Advice	743	212	107	1,062
Displaced People and Evacuations	442	126	63	631
Donation Needs or Offeres or Volunteering Services	1,827	522	261	2,610
Infrastructure and Utilities Damage	1,296	370	185	1,851
Injured or Dead People	1,754	501	251	2,506
Missing Trapped or Found People	281	80	40	401
Not Related or Irrelevant	1,642	469	234	2,345
Other Useful Information	4,004	1,144	572	5,720
# of Tweets	13,367	3,818	1,910	19,095

DATASET

The dataset used in experiments comes from CrisisNLP (Imran, Mitra, et al. 2016). The dataset consists of tweets posted during 11 different disasters that happened during 2013 to 2015. Each tweet is annotated by paid CrowdFlower Workers using situational awareness categories. The disasters in this collection can be classified as two categories: natural disasters and medical disasters. First category has 8 labels and second category has 7 labels. In this paper, we only used natural disasters data since medical disasters data does not contain sympathy labeled tweets.

As a result, we use 9 different disasters and the total number of tweets is 19,095. The detail information of the dataset labels/categories and the number of tweets in each category are shown in Table 3. All tweets are posted only in English. Since we have a purpose of extracting sympathy tweets, we mainly focus on Twitter postings that have label of "sympathy and emotional support" and treat this as positive class. All other labels are considered as the negative class. The number of tweets containing sympathy is 1,969 and the number of non-sympathy tweets is 17,126.

EXPERIMENTS AND RESULTS

Preprocessing

This step contains removing Twitter ID, hashtags, special characters and URLs. Moreover, OOV dictionary is used to process slangs and abbreviations. Lastly, we remove words and sentences with length smaller than 3.

CNN performance

The proposed CNN model, which is shown in Figure 1, is based on Y. Kim (2014) and Aipe et al. (2018). The CNN model consists of a convolutional layer followed by a max-pooling, concatenation and two fully-connected layers with batch normalization. More specifically, with regard to convolutional layer, there are 250 feature maps for each kernel size {2,3,4} and these feature maps are then max-pooled and concatenated as the input of fully-connected layer. Two dropout layers are added to reduce overfitting of neural network and drop rate is 0.5.

In experiments, the proposed CNN model, as well as the LSTM and Bi-LSTM models, are implemented on the disaster dataset described earlier. Ten different random seeds (from 5 to 50 with interval 5) are selected to split the pre-processed dataset and the final result is the average score of the 10 experiments. The proposed refined word embedding method is implemented in four different pre-trained word embeddings and tested on all deep learning frameworks. As we can observe from Table 4, all refined models outperform original models. More specifically, for example, refined CNN improves original CNN model with word embedding CrisisNLP, word2vec (GoogleNews), Glove and Fasttext by 0.25%, 0.57%, 0.48% and 1.21% respectively. Overall, CNN is generally the best performing algorithm with or without refinement model. It produces the best performance on word2vec, Glove and FastText embedding. Even though the refined Bi-LSTM model has the best result (75.08%) in CrisisNLP embedding, however the refined CNN with FastText embedding yields a better result (75.78%).

From our experimental results, we can also conclude that there exists at most 0.95%, 1.23%, 1.44% and 1.21% increase in CrisisNLP, word2vec, Glove and FastText embedding, respectively. Table 4 also shows that FastText word embedding generally performs better than other word embeddings. Four out of six models with FastText word embedding yield better performance over the others. To conclude, the refined CNN model with FastText embedding achieves the highest F1 score, which shows that the CNN architecture has the ability to solve specific text classification tasks such as sympathy detection and sentiment analysis.

Table 4. Performance of CNN and other frameworks on sympathy detection(F1 Score)

Model	CrisisNLP	word2vec	Glove	Fasttext_Crawl
Refined CNN	74.26	**75.39**	**75.42**	**75.78**
Refined LSTM	74.64	74.07	75.15	74.38
Refined Bi-LSTM	**75.08**	75.18	74.48	75.33
CNN	74.01	74.82	74.94	74.57
LSTM	74.03	72.84	73.71	74.38
Bi-LSTM	74.13	74.03	73.44	74.44

CNN vs. Baseline Classifiers

We compare our proposed refined CNN model with baseline machine learning algorithms such as Logistic Regression, Decision Tree, Stochastic Gradient Descent(SGD), AdaBoost , Support Vector Machine(SVM) and CNN-non-static model (Kim, 2014) with word2vec embedding in Table 5. In order to guarantee the correctness of comparisons, for each baseline model, the same training and testing samples are used and the final result is the average of 10 experiments.

From Table 5, we can see that the refined CNN model performs best in recall and F1 measure, which achieve 70.79% and 75.78%, respectively. We also observe that CNN-non-static model has the best result among baseline classifiers, followed by SVM and AdaBoost. Even though Logistic Regression has the highest precision score, it performs the worst in recall due to imbalanced data distribution. In general, CNN has better precision and recall score and thus it can be applied to detect sympathy sentences in highly skewed data.

Table 5. CNN vs. Baseline Classifiers

Model	Precision	Recall	F1-Score
Refined CNN	81.83	**70.79**	**75.78**
Logistic Regression	**95.2**	43.55	59.58
Decision Tree	64.44	66.67	65.47
SGD	90.69	55.77	68.96
AdaBoost	82.9	59.31	69.09
SVM	80.17	65.66	72.15
CNN-non-static (Kim, 2014)	87.99	64.60	74.40

CONCLUSION AND FUTURE DIRECTIONS

In this paper, we explore neural networks (e.g., CNNs, LSTMs) with different word embeddings for sympathy detection from Twitter disaster data. As a starting point for finding candidate donors, we successfully achieve the task of sympathy contents tweets detection using deep learning techniques. Moreover, we present a word stemming based refinement model to improve the existing pre-trained word embeddings. Instead of training new word embeddings, we can easily integrate the proposed refinement model into conventional word embeddings and improve the F1 score of text classification task such as sympathy detection. Experiments on disaster dataset show that proposed refined CNN model produces the best performance when compared with CNN and other deep learning frameworks. The performance of our model is significantly better than traditional classifiers.

In future work, it would be interesting to test our proposed model on various classes of disaster datasets, e.g. ‘donation needs or offers’. Also, it would be very interesting to see if our refinement model can improve text classification under different backgrounds. Moreover, an exciting direction to explore is the relations between sympathy and donations. An inspection of the CrisisNLP dataset reveals that there are many tweets that contain both sympathy and donation related contents. Several tweets that show a potential relationship between sympathy and donations are provided in Table 6. Based on this, our refinement model can also be extended as adding donation encoded features in the last layer of CNN and determine whether the performance of sympathy detection changes.

Table 6. Tweets containing 'Sympathy' and mentioning 'Donations'.

RT@RealLouisAndre: Sending out all my support for all people in #Chile all the prayers are with you, also u can donate @RedCross #PrayForChile
@justinbieber thanks for the challenge but I'm not able to do it so I just donated 30$ do the #ASL hope that makes up for it
RT@DAVIDsTEA: Our hearts go out to everyone in Nepal. Until May 4th, all profits from Nepal Black tea will be donated, to help fund

ACKNOWLEDGMENTS

We thank the National Science Foundation for support from the grants IIS-1802284, IIS-1741345, IIS-1526542 and CMMI-1541155. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the ocial policies, either express or implied, of the National Science Foundation. We also wish to thank our anonymous reviewers for their constructive comments.

REFERENCES

Aipe, A., Mukuntha, N., Ekbal, A., and Kurohashi, S. (2018). "Deep Learning Approach towards Multi-label Classification of Crisis Related Tweets". In: ISCRAM '18.

Alam, F., Ofli, F., Imran, M., and Aupetit, M. (2018). "A Twitter Tale of Three Hurricanes: Harvey, Irma, and Maria". In: ISCRAM '18.

Ashktorab, Z., Brown, C., Nandi, M., and Culotta, A. (2014). "Tweedr: Mining twitter to inform disaster response". In: *Proceedings of the 11th International Conference on Information Systems for Crisis Response and Management*. ISCRAM '14. University Park, Pennsylvania.

Baberini, M., Coleman, C.-L., Slovic, P., and Västfjäll, D. (2015). "Examining the effects of photographic attributes on sympathy, emotions, and donation behavior". In: *Visual Communication Quarterly* 22.2, pp. 118–128.

Baccianella, S., Esuli, A., and Sebastiani, F. (2010). "SentiWordNet 3.0: An Enhanced Lexical Resource for Sentiment Analysis and Opinion Mining". In: *Proceedings of the Seventh International Conference on Language Resources and Evaluation (LREC'10)*. Valletta, Malta: European Language Resources Association (ELRA).

Bautista, J. R. and Lin, T. T. (2015). "Social Support on Twitter: The Case of the Philippine's #Fallen44". In: *Cyberpsychology, Behavior, and Social Networking*.

Ben Lazreg, M., Goodwin, M., and Granmo, O.-C. (2016). "Proceedings of the Artificial Intelligence Applications and Innovations: 12th IFIP WG 12.5 International Conference and Workshops, AIAI 2016, Thessaloniki, Greece, September 16-18, 2016". In: *Information Abstraction from Crises Related Tweets Using Recurrent Neural Network*. Ed. by L. Iliadis and I. Maglogiannis. Cham: Springer International Publishing, pp. 441–452.

Bunce, S., Partridge, H., and Davis, K. (2012). "Exploring information experience using social media during the 2011 Queensland floods: a pilot study". In: *The Australian Library Journal* 61.1, pp. 34–45.

Caragea, C., Silvescu, A., and Tapia, A. H. (2016). "Identifying informative messages in disaster events using convolutional neural networks". In: *International Conference on Information Systems for Crisis Response and Management*, pp. 137–147.

Caragea, C., Squicciarini, A. C., Stehle, S., Neppalli, K., and Tapia, A. H. (2014). "Mapping moods: Geo-mapped sentiment analysis during hurricane sandy". In: *Proceedings of the 11th International Conference on Information Systems for Crisis Response and Management, University Park, Pennsylvania, USA, May 18-21, 2014.*

Derczynski, L., Meesters, K., Bontcheva, K., and Maynard, D. (2018). "Helping Crisis Responders Find the Informative Needle in the Tweet Haystack". In: ISCRAM '18.

Froyum, C. (2018). ""They Are Just Like You and Me": Cultivating Volunteer Sympathy". In: *Symbolic Interaction*.

Han, B., Ryzhov, I. O., and Defourny, B. (2013). "Efficient learning of donor retention strategies for the American Red Cross". In: *Proceedings of the 2013 Winter Simulation Conference: Simulation: Making Decisions in a Complex World*. IEEE Press, pp. 17–28.

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., and Meier, P. (2013). "Practical extraction of disaster-relevant information from social media". In: *22nd International World Wide Web Conference, WWW '13, Rio de Janeiro, Brazil, May 13-17, 2013, Companion Volume*, pp. 1021–1024.

Imran, M., Mitra, P., and Castillo, C. (2016). "Twitter as a Lifeline: Human-annotated Twitter Corpora for NLP of Crisis-related Messages". In: *Proceedings of the Tenth International Conference on Language Resources and Evaluation (LREC 2016)*. Portoroz, Slovenia: European Language Resources Association (ELRA).

Kaigo, M. (2012). "Social media usage during disasters and social capital: Twitter and the Great East Japan earthquake". In: *Keio Communication Review* 34.1, pp. 19–35.

Kim, S., Bak, J., and Oh, A. H. (2012). "Do You Feel What I Feel? Social Aspects of Emotions in Twitter Conversations". In: *Proceedings of the Sixth International Conference on Weblogs and Social Media, Dublin, Ireland, June 4-7, 2012*.

Kim, Y. (2014). "Convolutional Neural Networks for Sentence Classification". In: *Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing (EMNLP)*, pp. 1746–1751.

LeCun, Y., Bottou, L., Bengio, Y., and Haffner, P. (1998). "Gradient-based learning applied to document recognition". In: *Proceedings of the IEEE* 86.11, pp. 2278–2324.

Li, H., Caragea, D., and Caragea, C. (2017). "Towards Practical Usage of a Domain Adaptation Algorithm in the Early Hours of a Disaster". In: *Proceedings of the 14th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2017)*. France.

Li, H., Herndon, N., Caragea, D., and Caragea, C. (2017). "Disaster Response Aided by Tweet Classification with a Domain Adaptation Approach". In: *Journal of Contingencies and Crisis Management (JCCM), Special Issue on HCI in Critical Systems. In press*.

Mandel, B., Culotta, A., Boulahanis, J., Stark, D., Lewis, B., and Rodrigue, J. (2013). "A demographic analysis of online sentiment during hurricane Irene". In: Workshop on Language in Social Media.

Morstatter, F., Lubold, N., Pon-Barry, H., Pfeffer, J., and Liu, H. (2014). "Finding Eyewitness Tweets During Crises". In: *ACL 2014 Workshop on Language Technologies and Computational Social Science*. Baltimore, Maryland, USA.

Nagy, A. and Stamberger, J. (2012). "Crowd Sentiment Detection during Disasters and Crises". In: Proceedings of the 9th International ISCRAM Conference.

Neppalli, K., Caragea, C., Squicciarini, A., Tapia, A., and Stehle, S. (2017). "Sentiment Analysis during Hurricane Sandy in Emergency Response." In: *The International Journal of Disaster Risk Reduction (IJDRR 2017)*.

Neppalli, V. K., Caragea, C., and Caragea, D. (2018). "Deep Neural Networks versus Naïve Bayes Classifiers for Identifying Informative Tweets during Disasters". In: *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management*. ISCRAM '18. Rochester, New York, USA.

Nguyen, D. T., Al-Mannai, K., Joty, S. R., Sajjad, H., Imran, M., and Mitra, P. (2017). "Robust Classification of Crisis-Related Data on Social Networks Using Convolutional Neural Networks." In: *ICWSM*, pp. 632–635.

Nielsen, F. Å. (2011). "A new ANEW: Evaluation of a word list for sentiment analysis in microblogs". In: *CoRR* abs/1103.2903.

Pfitzner, R., Garas, A., and Scheweitzer, F. (2012). "Emotional Divergence Influences Information Spreading in Twitter". In: Proceedings to the 6th International AAAI Conference on Weblogs and Social Media. AAAI Press, pp. 543–546.

Purohit, H., Castillo, C., Imran, M., and Pandev, R. (2018). "Social-eoc: Serviceability model to rank social media requests for emergency operation centers". In: *2018 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM)*. IEEE, pp. 119–126.

Rudra, K., Sharma, A., Ganguly, N., and Ghosh, S. (2018). "Characterizing and Countering Communal Microblogs During Disaster Events". In: *IEEE Transactions on Computational Social Systems* 5.2, pp. 403–417.

Rudra, K., Ghosh, S., Ganguly, N., Goyal, P., and Ghosh, S. (2015). "Extracting situational information from microblogs during disaster events: a classification-summarization approach". In: *Proceedings of the 24th ACM International on Conference on Information and Knowledge Management*. ACM, pp. 583–592.

Sarda, P. and Lal Chouhan, R. (2017). "Extracting Non-Situational Information from Twitter During Disaster Events". In: *Journal of Cases on Information Technology* 19, pp. 15–23.

Schulz, A., Thanh, T., Paulheim, H., and Schweizer, I. (2013). "A Fine-Grained Sentiment Analysis Approach for Detecting Crisis Related Microposts". In: ISCRAM 2013.

Tanev, H., Zavarella, V., and Steinberger, J. (2017). "Monitoring disaster impact: detecting micro-events and eyewitness reports in mainstream and social media". In: *Proceedings of the 14th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2017)*. France.

Verma, S., Vieweg, S., Corvey, W. J., Palen, L., Martin, J. H., Palmer, M., Schram, A., and Anderson, K. M. (2011). "Natural Language Processing to the Rescue? Extracting" Situational Awareness" Tweets During Mass Emergency." In: *ICWSM*. Barcelona, pp. 385–392.

Yin, J., Lampert, A., Cameron, M., Robinson, B., and Power, R. (2012). "Using social media to enhance emergency situation awareness". In: *IEEE Intelligent Systems* 27.6, pp. 52–59.

Yu, L.-C., Wang, J., Lai, K. R., and Zhang, X. (2017). "Refining word embeddings for sentiment analysis". In: *Proceedings of the 2017 Conference on Empirical Methods in Natural Language Processing*, pp. 534–539.

Zahra, K., Imran, M., Ostermann, F. O., Boersma, K., and Tomaszewski, B. (2018). "Understanding eyewitness reports on Twitter during disasters". In: *ISCRAM 2018 Conference Proceedings*, pp. 687–695.

Zhang, Y. and Wallace, B. (2017). "A Sensitivity Analysis of (and Practitioners' Guide to) Convolutional Neural Networks for Sentence Classification". In: *Proceedings of the Eighth International Joint Conference on Natural Language Processing (Volume 1: Long Papers)*. Vol. 1, pp. 253–263.

Requirements for Software to Support the Use of Social Media in Emergency Management: A Delphi Study

S. Roxanne Hiltz
New Jersey Institute of Technology
roxanne.hiltz@gmail.com

Amanda Hughes
Brigham Young University
Amanda_Hughes@byu.edu

Muhammad Imran
Qatar Computing Research Institute
Hamad bin Khalifa University
mimran@hbku.edu.qa

Linda Plotnick
New Jersey Institute of Technology
Linda.Plotnick@njit.edu

Robert Power
Commonwealth Scientific and Industrial Research Organisation, Australia
robert.power@data61.csiro.au

Murray Turoff
New Jersey Institute of Technology
murrayturoff@gmail.com

ABSTRACT

Social Media contain a wealth of information that could improve the situational awareness of Emergency Managers during a crisis, but many barriers stand in the way. These include information overload, making it impossible to deal with the flood of raw posts, and lack of trust in unverified crowdsourced data. The purpose of this project is to build a communications bridge between emergency responders and technologists who can provide the advances needed to realize social media's full potential. We are employing a Delphi study survey design, which is a technique for exploring and developing consensus among a group of experts around a particular topic. Participants include emergency managers and technologists with experience in software to support the use of social media in crisis response, from many countries. The topics of the study are described and preliminary, partial results presented for Round 1 of the study, based on 33 responses.

Keywords

Social media, emergency management, crisis informatics, software requirements, Delphi method

INTRODUCTION

Social Media (SM) contain a wealth of information that could improve the situational awareness of Emergency Managers (EMs) during a crisis (Power et al., 2014; Palen and Hughes, 2018) but agencies are often reluctant to use SM, especially to gather unverified crowdsourced data (Plotnick et al., 2015; Plotnick and Hiltz, 2016). There is also a disconnect between the technologists who design and build automatic data processing systems to analyze SM data and the EMs who could benefit from using them. EMs do not know what is technically possible while technologists do not know what EMs want. Moreover, most existing systems rely only on a single SM data source (e.g., Twitter or Facebook). However, combining informative signals from multiple SM data sources could be useful in several ways e.g., determining the trustworthiness of SM data (Sherchan et al., 2013; Panteras et al., 2015), obtaining missing information (Mahmud et al., 2012), etc. Furthermore, these diverse SM data sources produce different content types. For instance, Flicker is best for images, YouTube for videos, whereas Twitter and Facebook are good for both text and images. Diversity in content types not only brings complementary information (Panteras et al., 2015), it is also useful to gain contextual understanding (Bontcheva et al., 2014). Despite the fact that complementary information in the form of either images or videos is readily available on many SM platforms, many past efforts to build automated systems for disaster response and management only focused on the textual content available on SM.

The purpose of this project is to build a communications bridge between emergency responders (for both governments and NGOs) working in Emergency Management and technologists who can provide the advances needed to realize SM's full potential. Moreover, we aim to solicit software requirements beyond the use of a single SM data source and single content type. To build this bridge, we employ a Delphi study, which is a technique for exploring and developing consensus among a group of experts around a particular topic (in this case, SM use in emergency management). Our study includes emergency responders and technologists from many domains and nations. The final product of the study will be a set of software requirements to better enable EMs to gather organized information from SM that is rated for trustworthiness and usable for decision making. Our overarching goal is to inform technologists of EM needs and to help EMs understand the feasibility of, and possible solutions to, meeting those needs.

In the sections that follow, we review the prior literature on software to support the use of social media by emergency managers, and briefly describe the Delphi method. We then describe the methods used in the Delphi study that is underway as of November 2018.

LITERATURE REVIEW

Social Media (SM) have become ubiquitous and are often used by emergency management organizations to disseminate information (Plotnick and Hiltz, 2016). However, prior studies (Hughes and Palen, 2012; Plotnick and Hiltz, 2016) suggest that there is great hesitation by emergency management (EM) organizations to use SM to collect data from the public during an emergency. This hesitation can create missed opportunities to improve situational awareness. Additionally, the public expects EMs to respond to their SM queries (Petersen et al., 2017) which cannot be done if EM agencies do not accept and use public SM posts.

Software Enhancements for Social Media Use in Emergency Management

There are many barriers to the use of social media (SM) for emergency management (EM), both technical and organizational. Social media are examples of "socio-technical" systems; meaning that their use and effectiveness are determined not only by the features and quality of the systems themselves, but also by social context factors such as user attributes (e.g., skills and training, or the lack of them), and by organizational norms and policies and resources (Power and Kibell, 2017). This is especially true of the use of SM as part of an emergency response management system, when the information that could be retrieved and used is generated by the public and communicated via a public commercial system, rather than by trusted information systems under organizational control (Plotnick and Hiltz, 2016). Some of these barriers can only be overcome through organizational changes, but others, especially those having to do with issues of information overload (thousands to millions of tweets and posts on a specific disaster; too much information arriving too fast and in a disorganized manner) and trustworthiness of SM posts (Tapia et al., 2011; Plotnick et al., 2015; Hughes and Shah, 2016), could be dealt with through software pre-processing systems.

Many studies describe possible software enhancements and systems that could improve the usability and usefulness of social media for disaster management. See (Imran et al., 2015) for an extensive survey of these technologies as of about four years ago. A great many of these new technologies for processing social media data incorporate both human efforts (e.g. crowdsourcing to create training sets for machine learning) and automated tasks (Imran, Mitra & Castillo, 2016). The multiple challenges facing software developers include real-time parsing of brief and informal messages, determining information credibility, and prioritizing useful information (Imran et al., 2018).

In a survey of 477 U.S. county-level EMs (Plotnick and Hiltz, 2018), several of the specific potential software enhancements described in (Imran et al., 2015) that could help overcome the limitations of SM for EMs were rated with the result being that they are perceived as highly useful. These enhancements included the ability to view SM data as generated by geographical location on a map-based display, and categorization of SM data by sub-events (e.g., rescue issues). However, that study had several limitations: participants were limited to U.S. county level EMs and many potential enhancements that have subsequently appeared in the literature were not included. The current study aims to overcome these limitations by including software developers and researchers related to SM in EM, from many countries and types of organizations, and adding features from systems described in recent studies and proposed and vetted by the study participants.

The Delphi Method

A Delphi study consists of two or more rounds of structured written exchanges between anonymous experts with different types of expertise relevant for a topic (Linstone and Turoff, 1975, 2011). It was developed in the 1950s to obtain expert input on a particular problem while allowing the participants to remain anonymous. The

expert panels are given questionnaires (mailed or online) and answer them at a time and place convenient to them. The technique is particularly useful in cases where the expert panel is dispersed over a wide geographic area, and for complex, multi-disciplinary problems (Hendela et al., 2017).

The Delphi method utilizes a series of questions over two or more rounds where each participant may suggest additional items for consideration in subsequent rounds. An important aspect of a Delphi is that experts are generally asked not only to rate various alternatives or issues or items, but also to explain their rating in comments. The comments often surface the underlying reason for disagreement on ratings, such as one person assuming that a related development is likely, while another expert assumes that it is not. After each set of questionnaires is completed, a facilitator summarizes the experts' inputs and then distributes the summary with another round of questions. The results are annotated to show which category(ies) of expert provided each feedback item. Thus, although anonymity is maintained, expert participants know the domain of the person providing feedback. This is helpful when the experts evaluate the feedback. The experts can then revise their answers from the first round in light of the ratings and comments of others, and add ratings of newly surfaced items or issues.

RESEARCH METHOD

Our objective is to foster a dialogue and exchange of knowledge among software developers, emergency managers, and researchers on SM, from different nations and types of organizations. Thus, we aim to obtain a representative "spread" of diverse opinions from different types of stakeholders, rather than a random or representative sample of any particular population.

Expert Recruitment

In recruiting possible participants, we cast a wide net, using our professional networks. This included sending invitation messages to researchers who had published papers in the social media tracks of recent ISCRAM-sponsored meetings; sending emails to lists of U.S. emergency managers; posting on Linked In discussion boards for EMs; personal messages to software developers; and requests for those initially invited to suggest other experts.

Following approval of the study by the New Jersey Institute of Technology Institutional Review Board (which included the consent form, screening questionnaire, and Round 1 questions of the Delphi), the initial invitation to participants was to complete a screening questionnaire. We used email to send the prospective participants a link to a Recruitment survey to build our expert panel prior to the actual Delphi. The Recruitment survey asked for information such as years of experience in EM and in software development for SM in EM, to make sure the volunteers qualified as "experts." We had hoped to obtain funding for the study, and the consent form stated that if we did obtain funding, those who completed both rounds would receive a $200 honorarium, payable to themselves or to a disaster-related charity, such as Doctors Without Borders. The screening questionnaire asked if they were willing to participate with or without such funding; it was reassuring that all but one of those who responded said they would participate "with or without" the funding, especially because we did not receive the funding. Since it was stated that the Delphi rounds of the study may take between 30 minutes and two hours per round, depending on how many comments a participant makes, this might have affected the response rate. There were 48 valid respondents to the Recruitment survey who indicated they were willing to participate out of over 400 prospective participants who received invitation messages or may have seen one on a discussion board.

We reviewed the responses to the Recruitment survey to confirm that the respondents were qualified by their expertise and experience to participate as members of the Delphi panel of experts. Those few respondents (N=9) to the Recruitment survey who were deemed unqualified either failed to complete the survey beyond the consent or did not have experience as a researcher, practitioner, and/or academic in the focus area of use of social media for emergency management. We maintained a list of the qualified respondents and then sent email to only these respondents with the link to the Round 1 Delphi questionnaire. The Recruitment survey took, on average, four minutes for the respondents to complete.

Delphi Questionnaires

Once the panel was formed, our Delphi process consisted of two rounds of surveys with feedback to the experts from each. This paper reports on the results of the Round 1 questionnaire.

The Round 1 questionnaire was a mix of qualitative and quantitative questions focused on four broad topic areas of participant demographics and experience, social media platforms, tool features, and recommendations. These topic areas were determined from the literature survey (particularly Imran et al., 2015 and Plotnick and Hiltz,

2016) and through iterative discussion within the research team. Once these broad topic areas were determined, they were refined and expanded into the specific survey questions, again through iterative discussion. In Round 1, we asked participants to rate the desirability and feasibility of a list of possible tools and features (provided by the research team) as well as to suggest others and to comment on software requirements. We were mindful of the trade-off between obtaining comprehensive answers from respondents and the time taken for them to complete the survey. With this in mind, the questions were structured as a mix of closed questions (using rating scales) and optional open-ended questions to provide further detailed information about the reasoning behind each rating. The Round 1 questionnaire is included as Appendix 1. We deployed the questionnaires using the Survey Monkey® system. Round 1 took place in late November 2018 through January of 2019. The Round 1 questionnaire took respondents an average of 36 minutes to complete.

For the second round, to occur in early 2019, the results will be fed back, including new suggestions and re-ratings, to try to reach a greater agreement. Data will be analyzed using SPSS® and a system that supports collaborative text content analysis, such as Dedoose®.

PRELIMINARY RESULTS OF ROUND 1

Characteristics of the Expert Panel Respondents

As of the end of January 2019, 33 of the invited and referred experts had responded to Round 1 of the Delphi study. The participants are diverse and well balanced among different types of background experiences, as shown below in Tables 1 and 2. A little less than half (16) are from the U.S., with 5 from Spain, two each from Germany and New Zealand, and one each from several other countries in Europe, Asia, the Middle East, and Canada.

Table 1. Work experience is in the domain of (check all that apply)

Software Design	NGO EM	Local gov't EM	State gov't EM	National gov't EM	Research
17	5	10	6	6	20

Note that participants could choose more than one domain. To further explore these work domains, we created mutually exclusive categories by first grouping participants as Practitioners if they were the EM for local, state, or National levels or an NGO. Then we coded as shown below:

Table 2. Work Experience Domains

	Frequency	Percent
Software Design only	2	6.1
Research only	6	18.2
Practitioner only	7	21.2
Software design and practitioner	4	12.1
Software design and research	7	21.2
Practitioner and research	3	9.1
Software design, practitioner and research	4	12.1
Total	33	100

In terms of relevant years of work experience related to social media use for EM, only 3 had 2 years or less; 10, 3-5 years; 12, 6-10 years; and 7, over 10 years. Given the recency of the emergence of this field of expertise, this is a very experienced set of experts. They are about 2/3 male, which reflects the gender makeup of the field.

Selected Preliminary Results

Systems to be Included

Many of the existing prototype systems for collecting, categorizing, and analyzing Social Media posts for disaster work with only one Social Media platform, most often Twitter or Facebook. The feasibility of creating systems for a single platform thus has been repeatedly demonstrated. However, it is not reasonable to expect EMs to use different software aids for different social media platforms and somehow integrate this information; 61% of the experts say it is not useful to have a system that uses only one SM platform. However, if the

software analysis system could handle both Facebook and Twitter, then the majority say it would be useful, as shown below:

Table 3. How useful to an EM would a system be that handles both Facebook and Twitter posts, but not other systems?

	Frequency	Percent
Not useful	0	-
2	1	3.0
3	3	9.1
4	2	6.1
5	4	12.1
6	9	27.3
Very useful	13	39.4
Cannot say	1	3.0
Total	33	100

Perceived as most useful would be a real-time system that handles all "major" SM platforms, customized for a particular country, as shown in Table 4.

Table 4. How useful would it be to have a real-time system that handles and integrates information from "all major" SM platforms customized for a particular country?

	Frequency	Percent
Not useful	0	-
2	0	-
3	0	-
4	1	3.03
5	4	12.12
6	4	12.12
Very useful	24	72.73
Cannot say	0	-
Total	33	100

What are these "major" platforms that should be included? They do vary by country of the respondent, but after Twitter and Facebook, mentioned by almost all, Instagram was checked by 21 out of the 33 participants, WhatsApp by 14, YouTube by 12, Flickr by 9, and several other platforms suggested by one to three.

Though this design requirement, to include all major SM platforms, is considered very important, the feasibility of doing so is questioned by many of the experts, as shown in Table 5. Thus, the panelists have identified in the first round, an important design challenge for the research community.

There were many comments from participants that highlighted the types of challenges posed, of which the following two quotes reflect frequent themes:

> "*There are several aspects to developing the SM platform that integrates multiple social platforms. One of the primary issues that I struggle with is the restrictions applied on the data – while Twitter is one of the best options, Facebook has a lot of content that is more promising – however, accessing FB is a massive struggle given the platform restrictions. Most often, creating public FB pages that many people 'like' and contribute to is one of the very few means of getting data but is highly restrictive, time consuming and potentially biased.*"

> "*I think it would be incredibly useful to have a system that integrated multiple social media platforms, especially if it could be tailored to a local area. However, there are a lot of challenges. First, one has*

to identify the most commonly used platforms (which is in flux). Second, there are many interoperability issues. Each social media platform has a different API, different types of data (and associations between those data), different privacy settings, different terms of services, and different ways of representing user data and messages."

Table 5. How feasible is it to implement a real-time system that handles and integrates information from "all major" SM platforms customized for a particular country?

	Frequency	Percent
Not feasible	0	-
2	2	6.06
3	3	9.09
4	3	9.09
5	6	18.18
6	2	6.06
Very feasible	4	12.12
Cannot say	13	39.39
Total	33	99.99

In analyses of the completed research, we will also present results for the desirability and feasibility of many specific features or capabilities that could or should be included in the ideal SM analysis system for the future. These were rated on 1 to 7 semantic differential scales; the scales are from 1 (not useful/not feasible) to 7 (very useful/very feasible). In the preliminary and partial results shown below in Table 6, the means for some of the most highly rated design options are reported with the "cannot say" responses removed.

Table 6. Desirable and Additional Features – MEANS

	Mean	Std Dev
Usefulness of viewing SM data as classified by geographic location with map-based display	6.74	0.682
Usefulness of viewing SM data as generated by categories of users	6.68	0.599
Usefulness of filtering incoming SM data for relevancy using NLP and expert ratings	6.68	0.599
Usefulness of a system that can automatically process SM images to identify relevant ones	6.55	0.675
Usefulness of a system that could dynamically extract emerging/unanticipated types of information	6.53	0.681
Usefulness of a system that can automatically process SM images to identify whether or not an image shows damage	6.48	0.890
Usefulness of a system that can identify the location of SM posts even without GPS tagging	6.44	1.162
Usefulness of the ability to view SM data as categorized by sub events	6.42	0.958
Usefulness of having a way to automatically integrate SM data into any major IS system currently used by EMs	6.38	1.264
Usefulness of a system that can automatically process SM images to identify injured, trapped, or displaced people	6.32	0.871

There is a clear pattern that the usefulness of features is rated higher (over 5.5 for all listed, including several not included in Table 6) than the feasibility of developing or having the features (not shown). Statistical significance is not calculated but it appears that while there is enthusiasm for the features, there is less confidence that they can be implemented.

Future analyses will look at how ratings of usefulness and feasibility of the various potential software tools vary by the nature of the work experience/background of the participants (practitioners vs. technologists and U.S. vs. other nations).

CONCLUSION

In this paper, we share preliminary findings from a Delphi Study designed to understand how software can better support the SM needs of emergency managers. Already experts in the study have identified many useful and desirable features for managing SM, but it seems that at least some of these features may be difficult to develop. Completion of the Delphi study and more analysis is needed to fully understand the feasibility of developing these features. Additionally, several of the experts who volunteered for the study noted its potential for providing needed information to guide the future of software development for social media use in emergency management. For instance, one emergency manager said, "Thank you for your work. We rely on SM as a primary means of public information and warning. Any improvements would have significant social benefit for our rural communities." Another Delphi participant exclaimed, "Excellent area of study! Much needed!" With the cooperation of the experts to complete the two rounds of the Delphi study, we hope to fulfill these expectations.

ACKNOWLEDGMENTS

Authors are listed in alphabetical order. We are grateful to all of the participants in this study, who gave generously of their time.

REFERENCES

Bontcheva , K., & Rout, D. (2014) Making sense of social media streams through semantics: A survey. *Semantic Web*, 5,5, 373-403.

Hendela, A.H., Turoff, M., Hiltz, S.R., and Fjermestad, J.L. (2017). A risk scenario for small businesses in Hurricane Sandy type disasters, In Proceedings of the Hawaii International Conference on System Sciences.

Hughes, A. L., & Palen, L. (2012). The evolving role of the public information officer: An examination of social media in emergency management, *Journal of Homeland Security and Emergency Management*, 9(1). https://doi.org/10.1515/1547-7355.1976

Hughes, A. L. and Shah, R. (2016) Designing an application for social media needs in emergency public information work, In Proceedings of the 19th International Conference on Supporting Group Work (GROUP 2016), ACM, NY, 399-408.

Imran, M., Castillo, C. Diaz, R. and Vieweg, S. (2015) Processing social media messages in mass emergency: A survey, *ACM Computing Surveys*, 47, 4, Article 67, July 2015.

Imran, M. Mitra, P. and Castillo, C. (2016) Twitter as a lifeline: Human-annotated twitter corpora for NLP of crisis-related messages, *In Proceedings of the Tenth International Conference on Language Resources and Evaluation (LREC 2016)* (23-28), European Language Resources Association (ELRA), Paris, France.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2018) Processing social media messages in mass emergency: Survey Summary, *In Proceedings of WWW 2018*, April 23-27, Lyon, France.

Linstone, H. and Turoff, M. (1975) The Delphi Method: Techniques and Applications, Reading, MA: Addison-Wesley.

Linstone, H. and Turoff, M. (2011) Delphi: A brief look backward and forward, *Technological Forecasting & Social Change*, 78(9), 1712–1719.

Mahmud, J., Nichols, J., and Drews, C. (2012) Where is this tweet from? Inferring home locations of Twitter users, *ICWSM*, 12, 511-514.

Palen, L. and Hughes, A.L. (2018) Social Media in Disaster Communication, *In Handbook of Disaster Research (2nd edition)*, Havidan Rodrigues, Joseph E. Trainor, William Donner and Antonio Paniagua Guzman (eds.), Springer, 497-518.

Panteras, G., Wise, S., Lu, X., Croitoru, A., Crooks, A., and Stefanidis, A. (2015) Triangulating social multimedia content for event localization using Flickr and Twitter, *Transactions in GIS*, 19(5), 694-715.

Petersen, L., Fallou, L., Reilly, P., and Serafinelli, E. (2017) Public expectations of social media use by critical infrastructure operators in crisis communication, *In Proceedings of the 14th International Conference on Information Systems for Crisis Response and Management,* Albi, France.

Plotnick, L. and Hiltz, S.R. (2018) Software innovations to support the use of social media by emergency managers, *International Journal of Human-Computer Interaction*, 34, 4.

Plotnick, L. and Hiltz, S.R. (2016), Barriers to use of social media by emergency managers, *Homeland Security & Emergency Management*, 13(2), January 2016.

Plotnick, L., Hiltz, S.R., Kushma, J.A., and Tapia, A. (2015) Red tape: Attitudes and issues related to use of

social media by U.S. county-level emergency managers, *In Proceedings of the ISCRAM Conference*, Kristianstad, Norway, May 24-27.

Power, R., and Kibell, J. (2017) The social media intelligence analyst for emergency management, *In Proceedings of the 50th Hawaii International Conference on System Sciences*.

Power, R., Robinson, B., Colton, J., and Cameron, M. (2014) Emergency situation awareness: Twitter case studies, *In Proceedings of Information Systems for Crisis Response and Management in Mediterranean Countries, ISCRAM-Med 2014*, Toulouse, France.

Sherchan, W., Nepal, S., & Paris, C. (2013), A survey of trust in social networks, *ACM Computing Surveys*, 445, 4.

Tapia, A. H., Bajpai, K., Jansen, B. J., & Yen, J. (2011) Seeking the trustworthy tweet: Can microblogged data fit the information needs of disaster response and humanitarian relief organizations, *In Proceedings of the 8th International ISCRAM Conference*, Lisbon, Portugal.

APPENDIX 1

The Round 1 questionnaire consisted of 64 questions organized into eight sections focused on the themes of: consent (2 questions), participant emergency management experience (1), social media platforms (9), desirable features (2), additional features (14), other features (28), recommendations (3) and participant demographics (5). There were 39 mandatory and 25 optional questions with a mix of 28 free text responses, one check box for multiple responses, three check boxes that also included a free text "other" option and 32 radio buttons for a single response. A full copy of the questionnaire is available from the authors upon request.

The questionnaire begins with details of the co-investigators and references the principle institution conducting the research before asking for the participants name as shown below.

Then an overview of the research and participant instructions are provided, as shown below, followed by a question to obtain explicit consent from the participant as shown in Figure 1 below.

PURPOSE:

The purpose of our project is to build a communications bridge between emergency responders for both governments and NGOs (non governmental organizations) working in Emergency Management and technologists and researchers who can provide the advances needed to realize SM's (social media) full potential. This will create a synergy that will lead to a set of software requirements to better enable EMs (emergency managers) to gather an organized set of information from SM postings that is rated for trustworthiness and usable for decision making.

DURATION:

My participation in this study will last for approximately 4 months (2 surveys several months apart), each requiring 1-2 hours to read background material and then answer thoroughly.

I have been told that my participation in this research is important for the success of the research and that the results of this research study are expected to produce the following benefits to society and for me as a subject.

BENEFITS FOR SOCIETY AND THE SUBJECT:

I have been told that the benefits are:

For society: recommendations and software requirements that will lead to more effective use of social media in crisis management, thus better protecting lives and property.

For you: opportunity to exchange information and ideas with peers about future needed software systems related to social media and emergency management.

PROCEDURES:

I have been told that, during the course of this study, the following will occur:

1. Potential participants will be asked to answer a short questionnaire indicating their interest and describing their relevant expertise.
2. From these applicants, a balanced panel of experts will be invited to participate in two rounds of online questionnaires (known as a "Delphi" design of a study, which consists of two or more rounds of structured written exchanges between anonymous experts with different types of expertise relevant for a topic.) Our topic is the desirability and feasibility of a number of software enhancements for managing social media input to emergency managers. Our 8 categories of experts include software developers, researchers, government emergency managers, and NGO emergency managers, from the U.S. and internationally.
3. Results of Round 1 will be fed back to participants, with Round 2 asking for re-ratings.
4. Participants will receive a draft report of findings prior to public release and invited to comment.

PARTICIPANTS:

I will be one of about 50 participants in this study.

EXCLUSIONS:

I will inform the researcher if any of the following apply to me:

1. You must be at least 18 years of age.
2. You must be fluent in written English.

RISKS/DISCOMFORTS:

I have been told that the study described above may involve the following risks and/ or discomforts:

As an online participant in this research, there is always the risk of intrusion by outside agents (i.e. hacking) and, therefore the possibility of being identified exists.

There also may be risks and discomforts that are not yet known.

I fully recognize that there are risks that I may be exposed to by volunteering in this study which are inherent in participating in any study; I understand that I am not covered by <redacted>'s insurance policy for any injury or loss I might sustain in the course of participating in the study.

CONFIDENTIALITY:

I understand that confidential is not the same as anonymous. Confidential means that my name will not be disclosed if there exists a documented linkage between my identity and my responses as recorded in the research records. Every effort will be made to maintain the confidentiality of my study records. If the findings from the study are published, I will not be identified by name. My identity will remain confidential unless disclosure is required by law.

Note 1: You will be assigned an ID based on this form; the file that matches the names and ID number will be kept separately and in a secure location; thus the data file that contains your answers will not be identifiable by name.

Note 2: If you agree, the final report on the study will list your name in a list of expert participants; if you do not explicitly agree, your name will not be included as a contributor to the research.

RIGHT TO REFUSE OR WITHDRAW:

I understand that my participation is voluntary and I may refuse to participate, or may discontinue my participation at any time with no adverse consequences. I also understand that the investigator has the right to withdraw me from the study at any time.

INDIVIDUAL TO CONTACT:

If I have any questions about my treatment or research procedures, I understand that I should contact the principal investigator at: <redacted>

If I have any additional questions about my rights as a research subject, I may contact: <redacted>

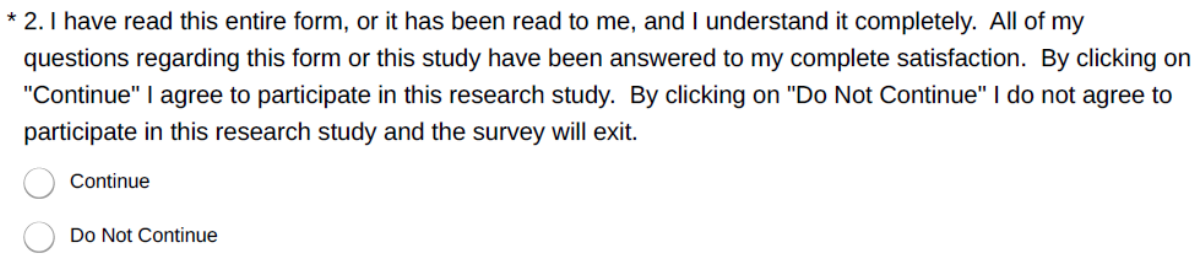


Figure 1: The Consent question.

The figures below show a selection of questions from the survey instrument. The question in Figure 2 corresponds to the results shown in Tables 1 and 2 above. Note the asterisk (*) next to the question number (3 in this case) indicates that the question is mandatory. This is an example of a check box question where the participant can select multiple responses.

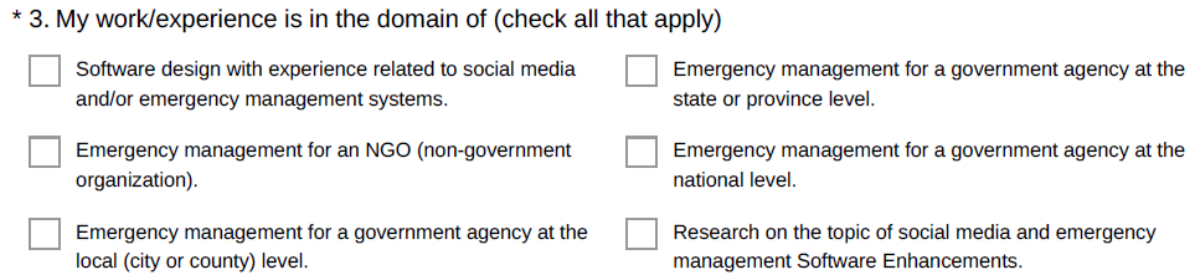


Figure 2: Participant work/experience.

Figure 3 shows the first four questions in the social media section of the survey where each is a radio button allowing only a single response. This section is preceded by an introduction describing the purpose of the survey in terms of identifying software enhancements as follows:

Our overarching goal is to make social media more usable for emergency managers (EMs) to gather and assess information from the public, to aid in "situational awareness" and decision making. In the research literature, there are many systems described that take the form of gathering information from social media (SM) posts during a crisis and processing it by organizing it, displaying it, and/or assessing its validity, etc. The purpose of this study is to gather expert wisdom about the potential usability and feasibility of a number of such possible software enhancements, in order to arrive at a set of requirements to guide future developments. We begin in this round with your ratings of an initial set of possible improvements that are already specified in the current literature, and then ask you to add additional improvements you think will help EMs more effectively use SM. Please supply as many comments as you can in the text boxes, in terms of additional ideas or reasons for your ratings.

If you do not have experience with software engineering, you should check "cannot say" when estimating feasibility of a possible enhancement

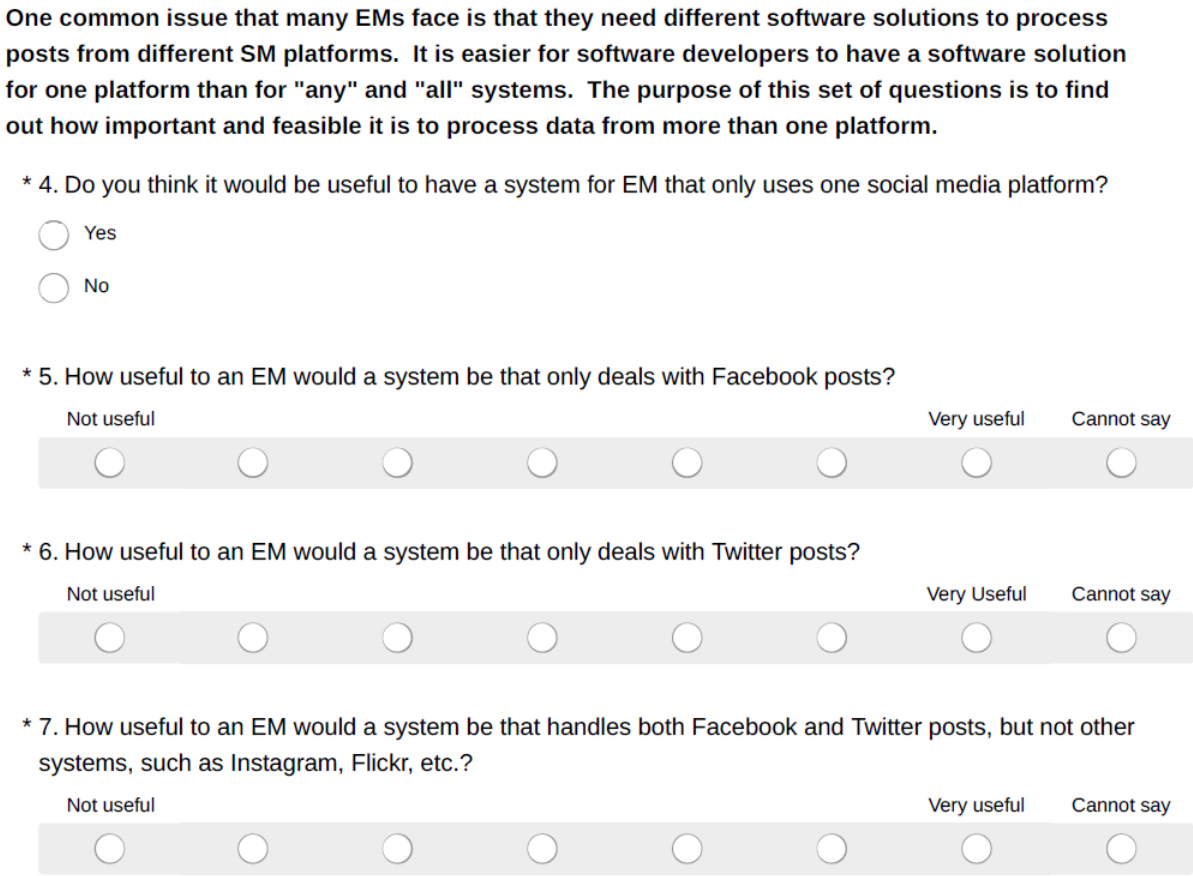


Figure 3: Example Social Media Platform questions.

Figure 4 shows the two "Desirable Features" questions while Figure 5 shows the first four questions from the "Additional Features" section. Questions 15 and 17 in Figure 5 show that some questions have multiple responses.

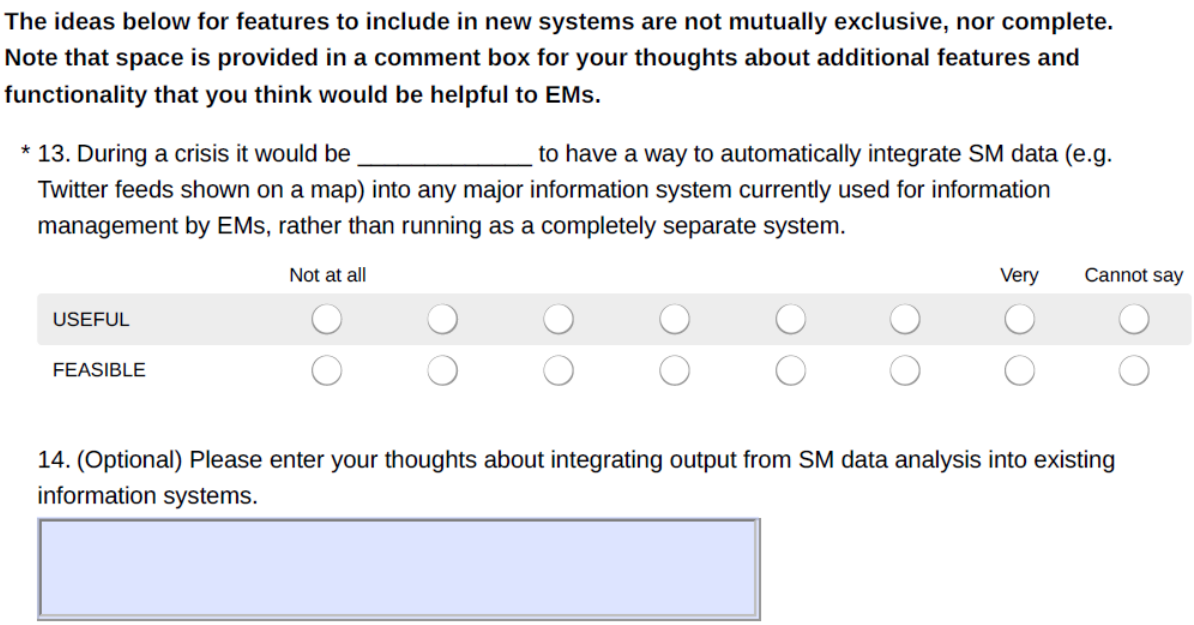


Figure 4: Desirable Features questions.

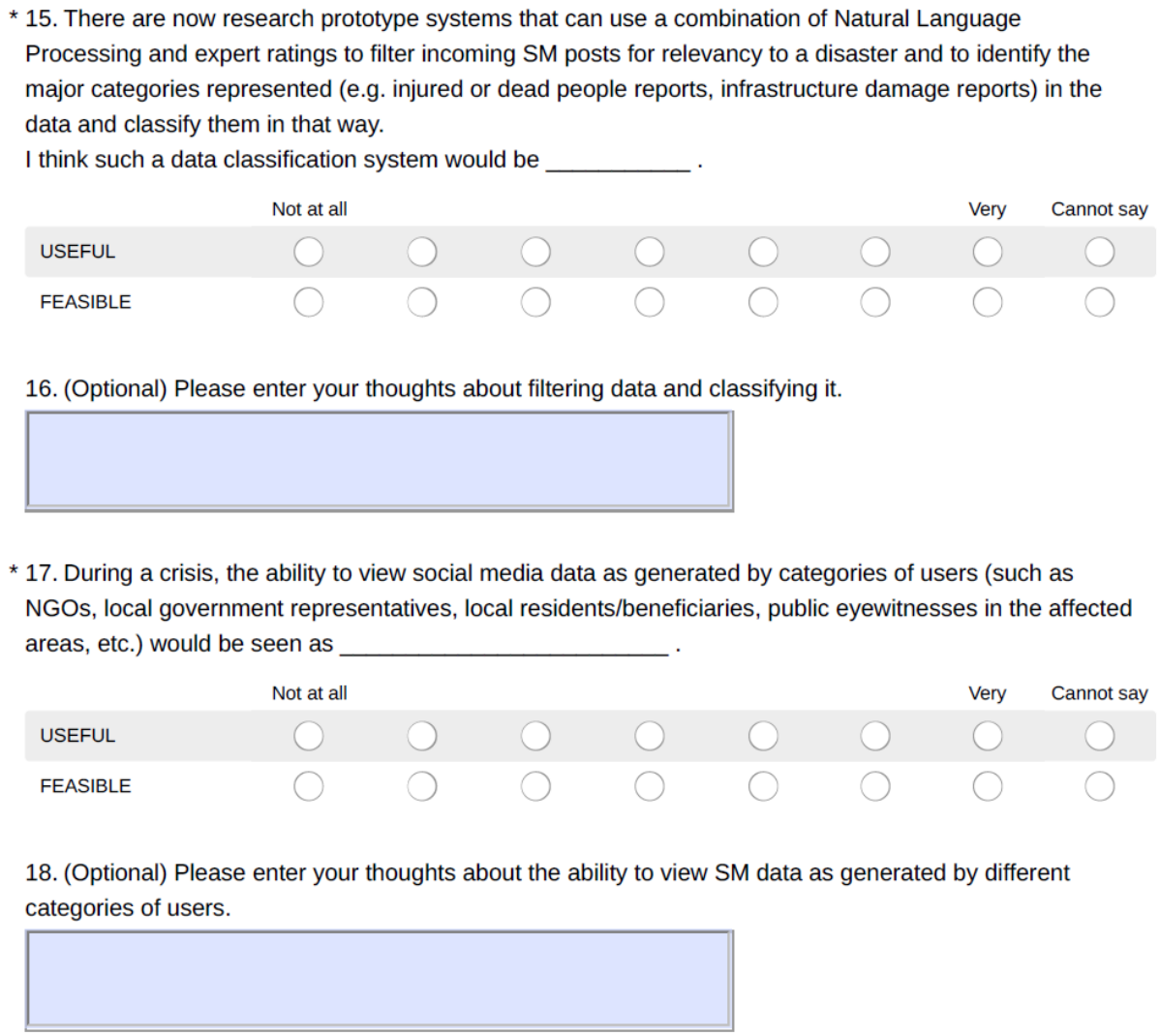


Figure 5: Example Additional Features questions.

Figure 6 shows the first four questions from the "Other Features" section.

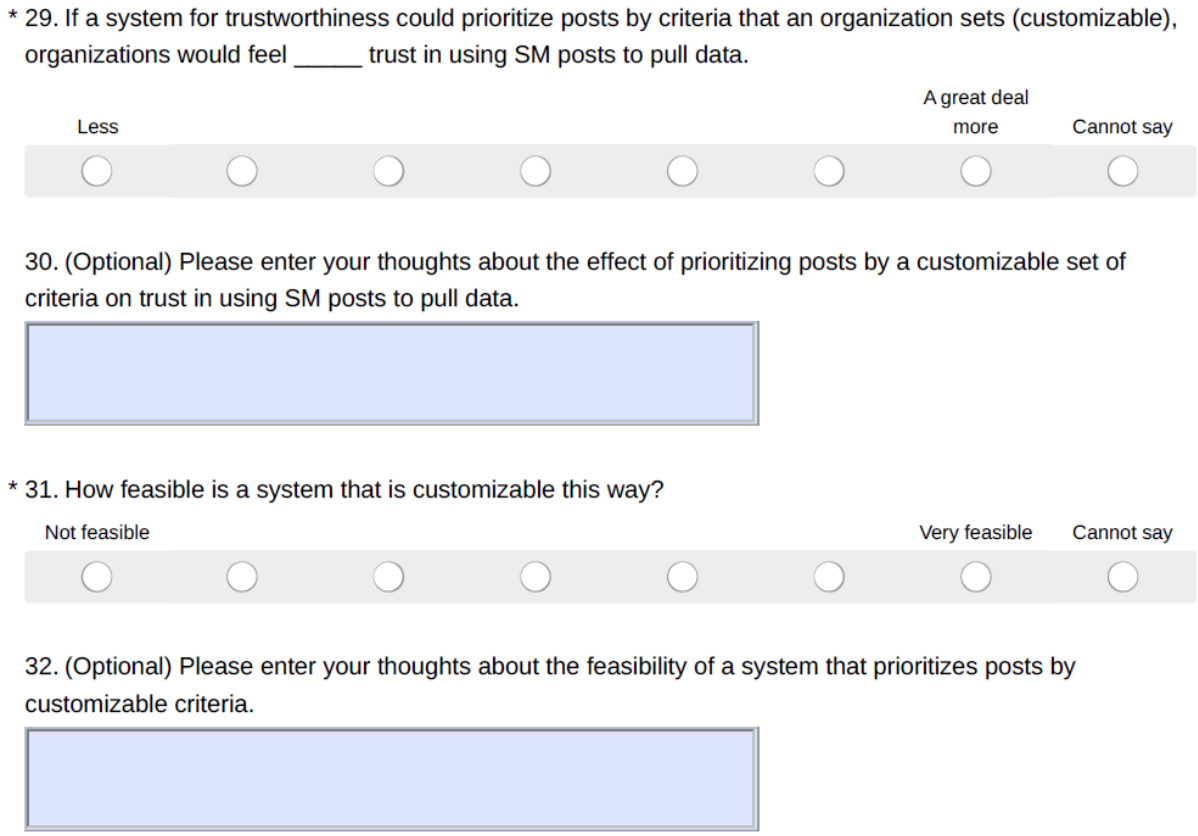


Figure 6: Example Other Features questions.

Figure 7 shows the three "Your Recommendations" questions and Figure 8 the participant demographics questions.

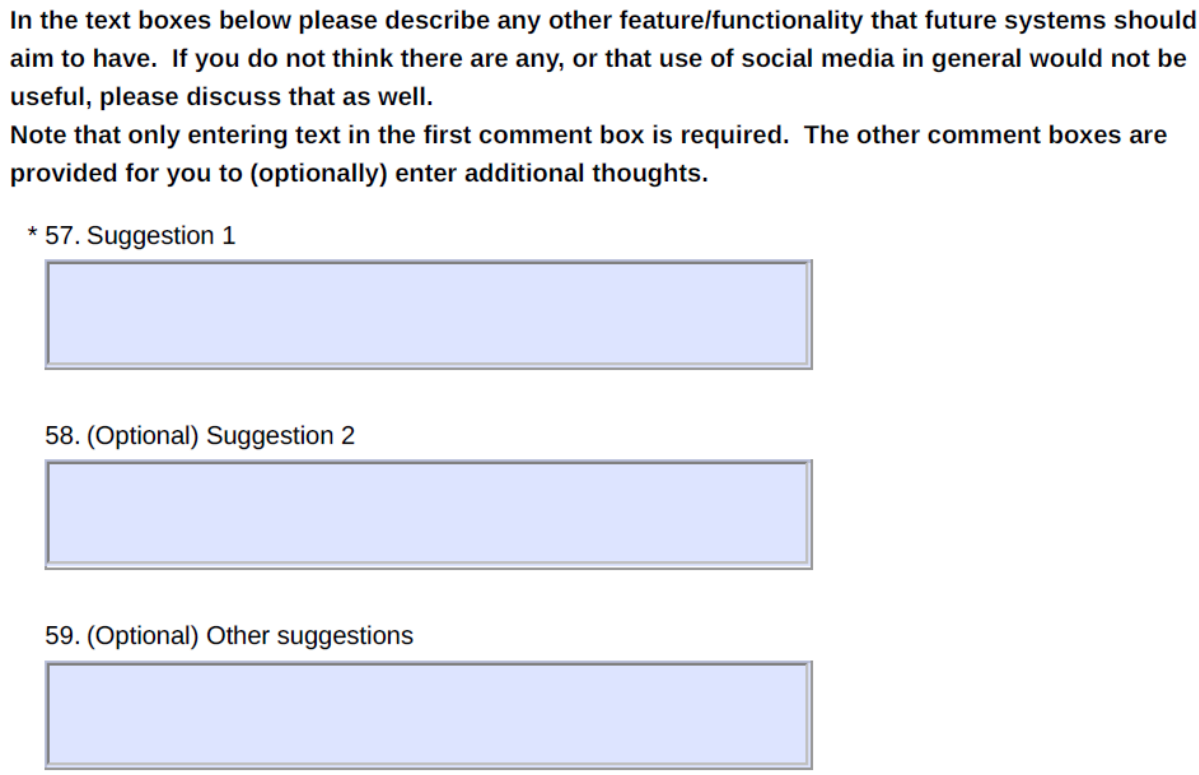


Figure 7: The three Your Recommendations questions.

* 60. I have been working, in some capacity, on projects or tasks related to social media for emergency management for:

- ◯ Less than 1 year
- ◯ 1 to 2 years
- ◯ 3 to 5 years
- ◯ 6 to 10 years
- ◯ more than 10 years

* 61. My age is:

- ◯ under 30
- ◯ 30 to 49
- ◯ 50 or over

* 62. I identify as:

- ◯ male
- ◯ female
- ◯ other

* 63. The primary country in which I am currently working is _____.

64. (Optional) Additional feedback: Please add any comments or issues, especially those that you think should be dealt with in round 2 of the Delphi.

Figure 8: Demographic questions.

Robust Filtering of Crisis-related Tweets

Jens Kersten*
German Aerospace Center, Jena, Germany†
jens.kersten@dlr.de

Anna Kruspe
German Aerospace Center, Jena, Germany
anna.kruspe@dlr.de

Matti Wiegmann
German Aerospace Center, Jena &
Bauhaus-Universität Weimar, Germany
matti.wiegmann@uni-weimar.de

Friederike Klan
German Aerospace Center, Jena, Germany
friederike.klan@dlr.de

ABSTRACT

Social media enables fast information exchange and status reporting during crises. Filtering is usually required to identify the small fraction of social media stream data related to events. Since deep learning has recently shown to be a reliable approach for filtering and analyzing Twitter messages, a Convolutional Neural Network is examined for filtering crisis-related tweets in this work. The goal is to understand how to obtain accurate and robust filtering models and how model accuracies tend to behave in case of new events. In contrast to other works, the application to real data streams is also investigated. Motivated by the observation that machine learning model accuracies highly depend on the used data, a new comprehensive and balanced compilation of existing data sets is proposed. Experimental results with this data set provide valuable insights. Preliminary results from filtering a data stream recorded during hurricane Florence in September 2018 confirm our results.

Keywords

Filtering, Convolutional Neural Networks, Natural Disasters, Twitter, Model Transferability.

INTRODUCTION

Several studies and use cases have demonstrated the great value and importance of analyzing social media streams, e.g. for rescue and helping activities in case of natural disasters and technical accidents (Reuter and Kaufhold 2018). Due to the huge and higly active user community distributed over the world, the ability to post messages from many sources as well as the accessibility of data streams via official APIs, research mainly focuses on Twitter. Furthermore, various labeled Twitter data sets related to crises and natural disasters are available.

As tweets posted during disasters are extremely varied, an automatic system needs to start by filtering out messages that do not contribute valuable information (Imran, Elbassuoni, et al. 2013). Existing approaches for filtering are keyword- or location-based, or utilize methods of natural language processing (NLP), visual analytics, or machine learning (Imran, Castillo, et al. 2015). An emerging availability of various labeled data sets recently enabled the successful application of deep learning to the problem of filtering (Burel and Alani 2018) as well as categorization of tweets into crisis-related information classes (Burel, Saif, et al. 2017, Nguyen, Al-Mannai, et al. 2017).

In this work, the robustness and accuracy of deep learning models is investigated for the task of filtering disaster-related tweets. Formulating filtering as a, preferably unambiguous, binary classification problem allows for experiments related to the impact of training data on the model quality. As investigated in (Stowe et al. 2018), a careful definition of thematic classes in filtering and classification is a crucial step. The authors distinguish between *related* and *unrelated* tweets, where the first class represents messages that are somehow related to disasters, and the

*corresponding author
†http://DLR.de/dw

latter class contains all off-topic posts. Since inter-annotator agreements around 92 % were obtained for this binary classification problem, this definition is also used here.

To develop robust filtering models, we compiled a new comprehensive and balanced dataset, which is one of the main contributions. More specifically, we are interested in performance differences of models covering various different event types (e.g. hurricanes, floods, earthquakes etc.) compared to models exclusively trained on one specific event type. The goal is to understand how to obtain accurate and robust filtering models and in particular how model accuracies tend to behave in case of new events. In contrast to other works, the application to real data streams is also investigated here.

In the first step, a balanced training data set covering several disaster types and containing approximately 66,000 tweets for both classes is compiled from several existing sets. Various event-specific and unspecific subsets of this training data set are then used to train and test a state-of-the-art Convolutional Neural Network (CNN). The experimental results show that the filtering task in case of new events can be tackled by global models covering several event types with acceptable F1-scores of 0.8 and better, while the standard deviation tends to be slightly higher than for models specifically trained for single event types. Preliminary results from filtering a data stream recorded during hurricane Florence in September 2018 further confirm the observed model behaviors.

RELATED WORK

It is easier than ever to search the web for information about disasters, but filtering out off-topic discussions from the ocean of online content remains difficult (Landwehr and Carley 2014). A potentially huge fraction of messages collected for the purpose of deriving information related to a given crisis will not be related to the considered event. This fraction depends on the specific collection method used and on other factors, such as the presence of off-topic messages using the same tags or keywords as the on-topic ones (Imran, Castillo, et al. 2015).

The official Twitter streaming API provides filtering by location, keywords, author, and others. An alternative for real-time stream filtering is the use of tools based on location or keywords, for example TweetTracker (Kumar et al. 2011). Following the approach of keyword-based search, a lexicon of crisis-related terms (*CrisisLex*), intended to be used for collecting and filtering microblogged communications in crises, was developed (Olteanu, Castillo, et al. 2014). Since also unrelated messages containing the keywords will be retrieved, this approach usually requires post-filtering, for example using human labeling, crowdsourcing or automatic classification (Imran, Castillo, et al. 2015). Furthermore, a significant fraction of relevant data might mistakenly be discarded if the keywords are not appropriate, e.g. when the event is new or has changed over time. In location-based filtering, a large percentage of tweets will be discarded because only a small fraction of around 2 % is usually geo-referenced (Burton et al. 2012).

In order to mitigate the aforementioned problems of keyword-based approaches, methods for analyzing the information contained in tweets have been investigated in several studies. Analyzing tweets using traditional NLP approaches is known to be challenging, for example because of the limitation to 280 characters, abbreviations, misspellings, emoticons, informal language with grammatical errors and varied vocabulary, improper sentence structure, and mixed languages (Ramachandran and Ramasubramanian 2018). In (Win and Aung 2017), the tasks tweet filtering, feature extraction and classification using a LIBLINEAR classifier are addressed. In case of training and testing tweets from the same event, maximum accuracies of around 91 % were obtained. For test tweets from unseen events (cross-domain experiment), significantly lower accuracies around 75 % were reported. In (Parilla-Ferrer et al. 2014) Naïve Bayes (NB) and Support Vector Machines (SVM) were used to automatically detect informative disaster-related tweets. While NB outperformed SVM in precision, SVM yielded a higher average F-measure (87.3 %) than NB (62.1 %). Even though methods from the area of NLP offer a wide range of possibilities for systematically and efficiently searching, filtering, sorting and analysing huge amounts of data, their application to social media data is a relatively new topic of research and confronts researchers with many questions and challenges (Gruender-Fahrer et al. 2018).

In (Kim 2014), CNNs were applied to the general task of sentence classification. Compared to 14 machine learning methods, a superior CNN performance was achieved for four of seven data sets, indicating a good model transferability. The approach of Kim was adapted to the problem of rapid classification of crisis-related data in (Nguyen, Al-Mannai, et al. 2017). The results demonstrate that classifying tweets in case of new events, i.e., when no event-specific data is available, is still possible with a decrease of AUC-scores in a range of 5 – 19 %. In (Burel and Alani 2018), Kim's CNN was applied to tweets for tackling the problems of filtering (*related* vs. *unrelated*) as well as classifying event types and information categories using data from the *CrisisLexT26* dataset (Olteanu, Vieweg, et al. 2015). F1-scores in the range of 80 – 84 % were obtained for the filtering task.

The results of recent works in the deep learning domain confirm the importance of high-quality data for training, also identified as one of the major challenges in social media analytics in (Stieglitz et al. 2018). Furthermore,

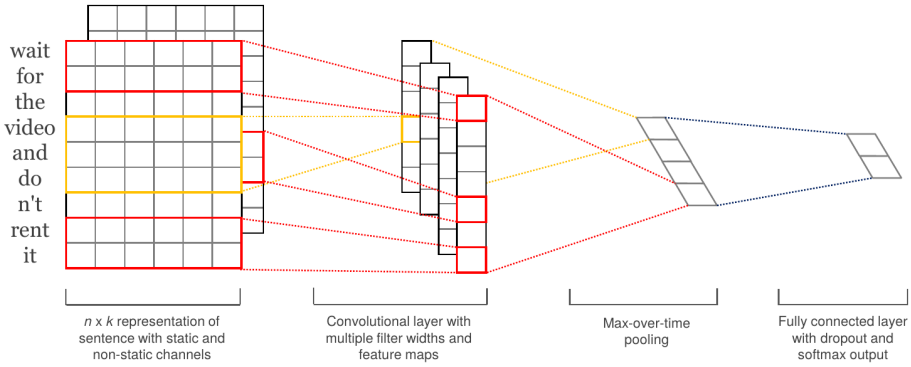


Figure 1. CNN for text classification as proposed in (Kim 2014)

the problem definition as well as other factors, like thematic class overlaps (Stowe et al. 2018) and the coverage of multiple event types (Periñán-Pascual and Arcas-Túnez 2018) may significantly affect model accuracy and robustness as well as its transferability to new events. Results of the studies discussed in this section only partially confirm these observations. With a focus on applying deep learning filtering models to real Twitter streams, the above-mentioned dependencies on data used for training is comprehensively and systematically investigated in this work. Since the CNN proposed by Kim has shown a great potential for crisis-related tweet filtering and classification, this model is utilized in our experiments.

CONVOLUTIONAL NEURAL NETWORKS FOR TWEET FILTERING

Motivated by the promising results in (Burel and Alani 2018) for tweet filtering (*related* vs. *unrelated*), per-tweet event type categorization and per-tweet information type classification, the same CNN architecture (Kim 2014) is utilized in this work (see figure 1). The approach was specifically developed for classifying sentences into diverse categories, e.g. question types or sentiments. At first, each message is pre-processed by applying a set of commonly used standard operations, i.e., lowercasing, multiple space replacing, normalizing URLs, usernames and hashtags, removing special characters, normalizing digits as well as tokenization. Each word of a tweet is then transformed into a real-valued vector of 300 elements.

Commonly used pre-trained embeddings are based on *word2vec* (Mikolov et al. 2013). In contrast, we use the embedding proposed in (Imran, Mitra, et al. 2016), which was specifically trained on 52 million crisis-related twitter messages. Hence, each tweet is represented as a matrix of size $n \times k$, where n is the maximum number of words occurring in the training data and $k = 300$ is the embedding vector length. In case the number of words is lower than n, zero padding is applied. Then, a convolutional layer applies m kernels of different widths w in parallel to the input matrix. We use standard values $m = 128$ and $w = (3, 4, 5)$, because parameter variation did not affect the results significantly. Global max-pooling is performed after each of these convolutional layers, and the results are concatenated. This new embedding is then fed into a fully connected layer with a dropout rate of 0.5 to determine the final class.

DATASET

Various comprehensive labeled crisis-related Twitter data sets are available, enabling the application and evaluation of machine learning methods. Besides a categorization of event types and information classes, labels for relatedness, relevance or informativeness are usually provided or can be derived from the data, for example by merging all information class labels to a *related* class. However, from a machine learning point of view, a significant imbalance of available class instances in nearly all datasets can be observed. Since crisis-related tweets are often pre-selected by using specific keywords or hashtags, the number of related tweets is usually higher than the number of unrelated tweets. Furthermore, not all common types of disaster events are covered by all data sets. To overcome these issues, we compile a new comprehensive and balanced training data set for filtering tweets related to disasters of different types. In this work, the labels from five common data sets are transformed to comply with our definition (*related* vs. *unrelated*). To increase the low number of *unrelated* tweets, the *Events2012* (McMinn et al. 2013) data set is utilized. This set contains relevance judgments for 150,000 tweets covering more than 500 non-crisis events from a broad range of topics. An overview of the resulting data set is provided in table 1.

Table 1. Composition of the proposed data set

Data set	*Tweet count related*	*Tweet count unrelated*	*Covered event types*
Events2012 (McMinn et al. 2013)	3,612	48,531	Disasters and accidents, 500 other topics, like sports, arts, culture and entertainment
CrisisLexT26 (Olteanu, Vieweg, et al. 2015)	24,581	3,352	Earthquake, flood, wildfire, meteor, typhoon, flood, train crash, explosions, building collapse, bombings
CrisisNLP (Imran, Mitra, et al. 2016)	22,381	-	Earthquake, hurricane, flood, typhoon, cyclone, ebola, MERS
CrisisMMD (Alam et al. 2018)	11,524	-	Hurricane, earthquake, wildfire, flood
Epic (Stowe et al. 2018)	4,578	14,809	Hurricane
Sum	66,692	66,692	

According to our definition, the *CrisisLexT26* classes *related and informative* as well as *related - but not informative* are merged to the target class *related*. From *CrisisMMD* (Alam et al. 2018), only tweets labeled as *informative* are used as *related*. Since tweets from class *not informative* may or may not be related to crisis events, they are not used here. This also applies to *CrisisNLP* (Imran, Mitra, et al. 2016), where the class *not related or irrelevant* might still contain crisis-related tweets. *Epic* (Stowe et al. 2018) uses the same problem definition as this work. From *Events2012*, tweets related to disasters and accidents are used for the target class *related*. In order to achieve perfect class balance, randomly sampled tweets from all other non-crisis topics of this data set are used for the class *unrelated*.

EXPERIMENTAL RESULTS

In this section, the goal is to evaluate the impact of the proposed data set compared to other related works as well as to investigate the performance behavior and robustness of models covering a broad range of event types (in the following denoted as "global models") compared to models specifically trained on single events (in the following denoted as "local models"). Local models individually trained on hurricane or flood event data sets are evaluated and compared to global models trained with the complete data set. Hurricanes and floods are chosen because of the their frequent occurence as well as the availability of data. Furthermore, the transferability of local and global models to new events is investigated.

The following experiments are conducted: First, global model performances are compared to a benchmark method as well as to local models trained for specific event types. In contrast to other studies, where accuracy measures obtained during cross-validation are reported (e.g. in (Burel and Alani 2018)), we use independent test data excluded from cross-validation. Model transferabilty is evaluated by using test data from unseen events. Secondly, we investigate how well local models perform in case of other event types. To this end, local flood models are applied to hurricane data and vice versa. Third, since available labeled data sets usually represent a pre-selected subset, we evaluate the transferability of our models to new Twitter data streams. First results for filtering ~1,120,000 geo-located tweets from the impact area during hurricane Florence (September 12-19, 2018) as well as after the event (January 08-15, 2019) are presented.

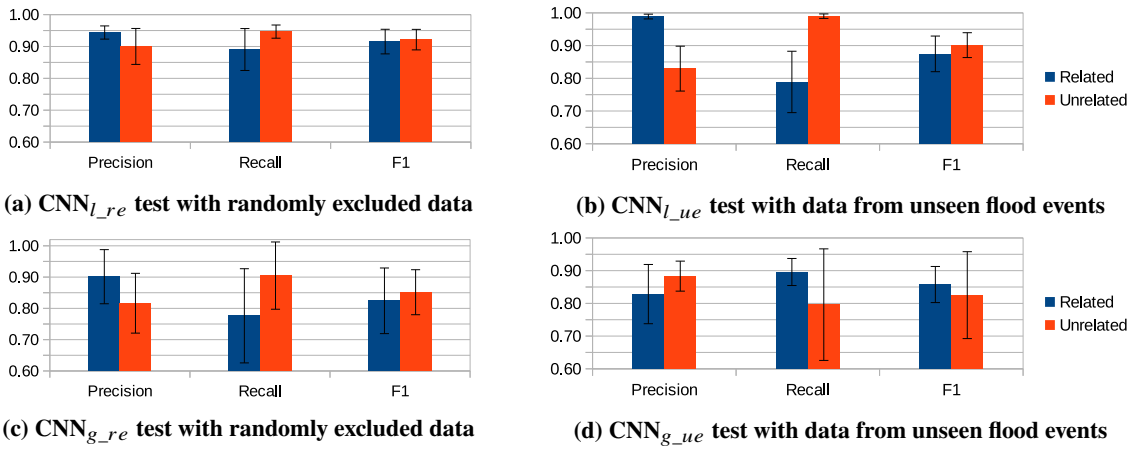
Flood events: Global versus local models

The five data sets listed in table 1 cover the following six flood events: Phillippines 2012, Alberta 2013, Manila 2013, Queensland 2013 (all from *CrisisLexT26*, ~ 1,000 tweets per event), Pakistan 2014 (*CrisisNLP*, ~ 2,000 tweets) and Sri Lanka 2017 (*CrisisMMD*, ~ 800 tweets). Whereas global models are trained by using the full proposed data set, local models are trained solely based on the above-mentioned flood data sets. Perfect class balance is achieved by randomly sampling the required amount of *unrelated* tweets from the *Events2012* data set. In addition to typically used 10-fold cross-validation (CV), we exclude 10 % randomly sampled tweets from CV for independent testing. In order to test the the models' transferability, each of the events is successively excluded for training local and global models, and is instead used for testing. Hence, a total number of 120 models is trained and evaluated in this experiment, where for each omitted flood event 10-fold CV for a local and a global model is conducted. Besides commonly used averaged results for precision, recall and F1-measure, the standard deviation of these scores is analyzed here as well.

In figure 2, the obtained results for the local and global models averaged over all CVs as well as the six flood events are presented. In case of local model validation with randomly excluded data (figure 2a), F1-scores around 0.92 are obtained. As expected, with test data from unseen events, the local models perform slightly worse (figure 2b). Nonetheless, the average F1-scores are 0.88 and 0.90 for the classes *related* and *unrelated*, respectively. In contrast, the global models yield F1-values between 0.82 and 0.85 and therefore perform worse than the local models. Furthermore, the standard deviations for global models tended to be higher. In table 2, the results are compared to those reported in (Burel and Alani 2018), where the same model and problem definition with *CrisisLexT26* data were used (CNN_{base}). To the best of our knowledge, this represents the best results obtained for filtering (*related* vs. *unrelated*) up to now.

Table 2. Local and global models tested with randomly excluded and unseen event data, where l=local, g=global, re=randomly excluded data, ue=unseen event data

		Related			*Unrelated*		
Event	*Model*	*Precision*	*Recall*	*F1*	*Precision*	*Recall*	*F1*
Flood	CNN_{l_re}	0.944±0.021	0.891±0.066	0.915±0.039	0.900±0.056	0.947±0.021	0.922 ±0.032
	CNN_{l_ue}	0.989±0.007	0.789±0.094	0.875±0.054	0.830±0.069	0.990±0.007	0.901 ±0.038
	CNN_{g_re}	0.901±0.087	0.776±0.151	0.824±0.105	0.816±0.096	0.905±0.108	0.852 ±0.072
	CNN_{g_ue}	0.828±0.091	0.896±0.041	0.858±0.055	0.883±0.046	0.796±0.171	0.825 ±0.133
Hurricane	CNN_{l_re}	0.900±0.061	0.846±0.188	0.865±0.134	0.892±0.122	0.927±0.033	0.906 ±0.078
	CNN_{l_ue}	0.755±0.013	0.802±0.273	0.747±0.181	0.895±0.048	0.753±0.112	0.811 ±0.038
	CNN_{g_re}	0.904±0.095	0.775±0.152	0.825±0.108	0.810±0.102	0.905±0.124	0.846 ±0.087
	CNN_{g_ue}	0.766±0.222	0.863±0.124	0.805±0.185	0.892±0.151	0.803±0.179	0.839 ±0.147
	CNN_{base}	0.839	0.838	0.838			



(a) CNN_{l_re} test with randomly excluded data

(b) CNN_{l_ue} test with data from unseen flood events

(c) CNN_{g_re} test with randomly excluded data

(d) CNN_{g_ue} test with data from unseen flood events

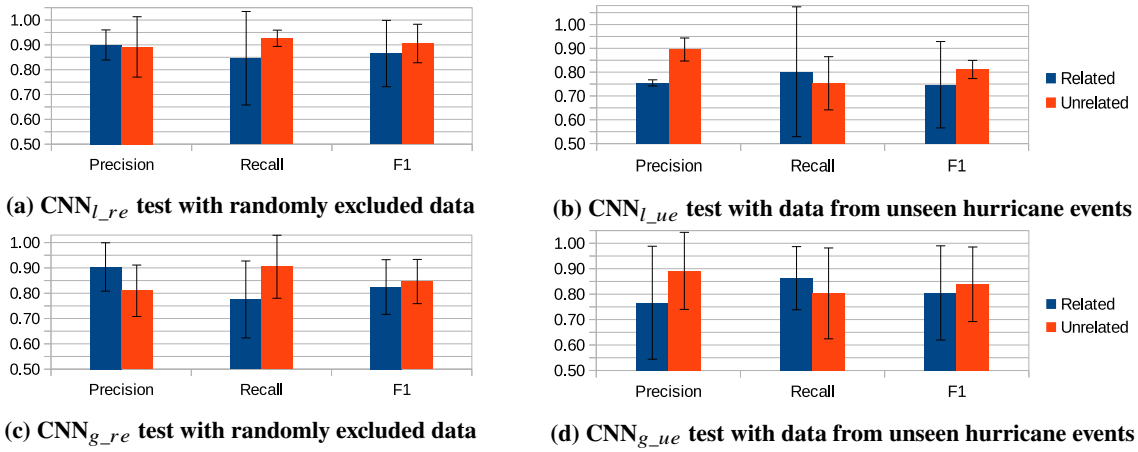
Figure 2. Averaged results of local and global models tested with randomly excluded and new flood event data

Hurricane events: Global versus local models

The data sets listed in table 1 cover the following five different hurricane events: Sandy 2012 (*Epic*, ~ 20,000 tweets), Odile 2014 (*CrisisNLP*, ~ 2,000 tweets), Harvey 2017, Irma 2017, Maria 2017 (all from *CrisisMMD*, ~ 4,000 tweets per event). A total number of 100 models is trained and evaluated in the same manner as described above in this experiment. According to figure 3 and table 2, local and global models tested with randomly excluded data behave similarly to flood-related models. Testing with different unseen hurricane-related data sets results in F1 drops between 0.007 and 0.12. An intersting observation is that global models yield higher F1-scores than local models in case of unseen events.

Local model transferability to other events

Even though local models tend to be more accurate and robust in our experiments, a practical application might be challenging. Models trained on specific event types would have to be applied to a data stream in parallel. The per-tweet model votes can then be used for filtering as well as a decision regarding the relatedness to specific



(a) CNN$_{l_re}$ test with randomly excluded data

(b) CNN$_{l_ue}$ test with data from unseen hurricane events

(c) CNN$_{g_re}$ test with randomly excluded data

(d) CNN$_{g_ue}$ test with data from unseen hurricane events

Figure 3. Averaged results of local and global CNNs tested with randomly excluded and new hurricane event data

event types. Even though this would provide valuable additional information, a decision cannot be made in case of ambiguous model votes. In this context, the cross-event performance of local flood and hurricane models is investigated in this experiment. Averaged results and standard deviations for all local models applied on other event types are shown in table 3. Compared to the results of local models applied to data from the same event type,

Table 3. Scores for cross-event application of local flood (F) and hurricane (H) models

	Related			*Unrelated*		
Model→ Event	*Precision*	*Recall*	*F1*	*Precision*	*Recall*	*F1*
F→ H	0.907±0.124	0.491±0.146	0.629±0.139	0.710±0.081	0.975±0.017	0.819 ±0.050
F→ F	0.989±0.007	0.789±0.094	0.875±0.054	0.830±0.069	0.990±0.007	0.901 ±0.038
H→ F	0.809±0.101	0.785±0.165	0.779±0.092	0.807±0.106	0.791±0.113	0.789 ±0.062
H→ H	0.755±0.013	0.802±0.273	0.747±0.181	0.895±0.048	0.753±0.112	0.811 ±0.038

obtained F1-scores are up to 0.25 lower, where hurricane models applied to flood data perform better than vice versa. For *related* tweets, especially in case of flood models applied to hurricane data, the recall drops significantly.

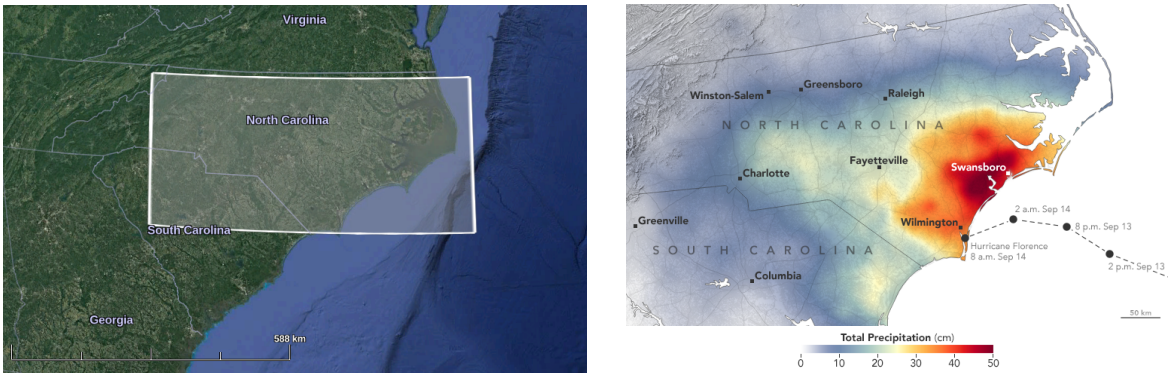
Hurricane Florence: Global model transferability

Analyzing the tweet content without preliminary keyword-based filtering, as proposed in this work, implies a significantly higher occurence of unrelated tweets, which is usually not represented in labeled data sets. We therefore acquired $\sim 600,000$ tweets during hurricane Florence from September 12th to 19th, 2018, using the Twitter API. In order to avoid effects of keyword-based filtering, we applied location-based filtering by defining an area of interest (AOI) as shown in figure 4a. Forecast services estimated that this would be the mainly affected area for which heavy rainfall was expected as well (figure 4b).

Since only a fraction of all tweets is known to be geo-referenced, this approach might again introduce bias. However, we assume that sampling geo-referenced tweets provides a more representative subset of all tweets than sampling by keywords. Another advantage of this approach is that tweets from directly affected individuals are collected, whereas tweets from users who are not directly involved, but contribute to discussions are discarded.

The results of our global model applied to the Florence data allow for several further analyses. As a first result, the temporal distribution of *related* and *unrelated* tweets binned into intervals of two hours is shown in figure 5. A daily tweet activity pattern with maximum values of $\sim 10k - 12k$ until around midnight can be observed. 14.9 % of all tweets are classified as *related* to a disaster event. Due to the current lack of labels for this data set, the results are analyzed qualitatively in order to gain first insights (see discussion).

The same model is applied to a second data set acquired for the AOI in figure 4a during a non-disaster period (January 08-15, 2019). The corresponding histogram shown in figure 6 has a similar pattern as the one generated for the event period. During the disaster, $\sim 88,400$ tweets were identified as *related*, whereas in the second period around half of this amount was detected ($\sim 43,700$ tweets). With a total number of $\sim 526,000$ tweets recorded in January 2019, 8.3 % of these are classified as *related*. Selected examples are listed in table 4. The highest-ranked



(a) Defined AOI **(b) Rainfall and hurricane trajectory (Sep. 13-14)**

Figure 4. Defined AOI (Google Maps 2018) and precipitation map (NASA Earth Observatory 2018)

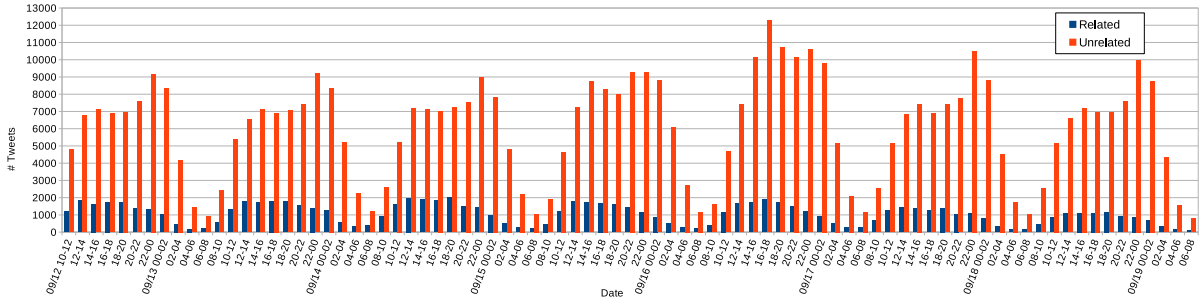


Figure 5. Filtering results during hurricane Florence, September 12-19, 2018

related tweets demonstrate that even though Florence seemed not to be a huge topic during January, other general crisis-related aspects as well as the heavy 2018 California wildfires are discussed. The *related* examples with a likelihood of 0.9 indicate that many *unrelated* tweets might be misclassified. Classification examples for class *unrelated* with softmax values between 1.0 and 0.5 in turn indicate a large likelihood that these are correctly classified.

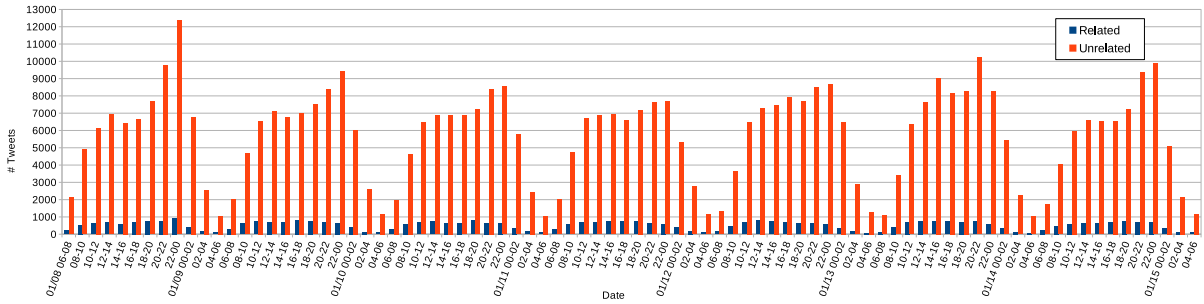


Figure 6. Filtering results during a non-crisis period, January 08-15, 2019

DISCUSSION

In this study, our comprehensive and balanced data set leads to better results for tweet filtering compared to other studies, in which the same CNN architecture and similar hyperparameters were used. We choose a binary and objective classification problem without further semantic interpretations, like the informativeness or usefulness of related tweets. Taking into account that inter-annotator agreement of around 92 % was obtained for this definition in (Stowe et al. 2018), our F1-scores in a range of 75 – 92 % for local models as well as 80 – 86 % for global models are satisfying.

Event type-specific differences of model accuracies can partially be explained by the complexity of disaster types. The fact that flood events represent one of several different sub-event types typically occuring during or after hurricanes might be the main reason for lower scores and higher standard deviations for hurricane models.

Table 4. Selected filtering results for the non-crisis data set, January 2019

	Classified as related	
Rank	*Tweet text*	*Softmax*
1	@userID I think the fact he's threatened to do it for several weeks, negates an emergency. Fires, hurricanes, storms, climate change, threat to democracy, stopping russian influence.....those are emergencies	
2	@userID FEMA helps victims of fires. You don't know anything about forest fires.	
3	#hash #hash #hash Trump Halts FEMA Funds for Calif. Wildfires, Forest Management URL #hash via @userID	1.0
4	How's the beaches in Puerto Rico Chuck?	
5	After the fire: Helping firefighters cope with tragedy. URL	
...	...	...
4946	The golf walls are taking shape. URL	
4947	How is it getting through TSA? I kinda wanna get the agents like a card or something lol	
4948	@userID @userID Okay for Comey to travel to all the FBI offices, but Whitaker going to USA offices? Such a low priority for Nadler	0.9
4949	@userID So the Democrats are concerned about the government being re-opened and the 800K plus ancillary people also impacted - can get back to work and paid. Meanwhile, Baby Trump / GOP are only concerned with his 'wall'. Use the damned money already available for border security.	
4950	Council is hearing an update about installing sidewalks on Oxford Road. We've got a couple of folks who aren't happy about the idea. This was first brought up in 2015. #hash URL	
	Classified as unrelated	
Rank	*Tweet text*	*Softmax*
1	Loyalty Loyalty Loyalty Loyalty Loyalty Loyalty Loyalty ... That's all I ask for	
2	@userID @userID Total manure! Dynasty? Playoffs? Playoffs? Dynasty?	
3	*sings* loyalty loyalty loyalty	1.0
4	MVP MVP MVP MVP MVP MVP [EMO]	
5	POLLS ....??....POLLS ...? or PLAYOFFS ?...SMH URL	
...	...	...
482201	Slow traffic in #hash on I-40 WB between Lk Wheeler Rd - Exit 297 and Gorman St - Exit 295, accident at Gorman St - Exit 295 #hash	
482202	When @userID comes on.....you be on some other Shut [EMO] #hash [EMO] #hash #hash #hash #hash @ Burlington, North Carolina URL	0.5
482203	EXCUSE ME?!? Why is blue hair hitting like this?	
482204	To2 w/ @userID for CWL Fort Worth be on to play rn Under @userID Have 600+ pps. We need a Main ICR, 2 Saugs. Be good don't waist our time!!!!! Rt if you the homie [EMO]	
482205	I'm at @userID Home Improvement in Cary, NC URL	

According to figures 2a-2c, the flood-related local and global models show a general accuracy pattern, in which recall is lower than precision for class *related* and vice versa for class *unrelated*. A high precision for *related* tweets indicates a low percentage of *unrelated* misclassified tweets. A lower recall for *related* tweets indicates that misclassifications for *related* tweets are more likely. An interesting observation is that the relations are intensified for local models tested with unseen event data, i.e., precision and recall for *related* are around 0.99 and 0.80, respectively, and vice versa for *unrelated*. F1 standard deviations of $0.03 - 0.05$ for the local flood models indicate a high robustness. Furthermore, the averaged scores are higher compared to the baseline model.

For the corresponding hurricane-related models (figures 3a-3c, table 2), other relations as well as lower scores and higher standard deviations can be observed, where the latter two can be explained by the aforementioned heterogeinity of possible sub-events in case of hurricanes. Compared to a baseline value of 0.84 for precision, recall and F1, corresponding average values of 0.90, 0.81 and 0.85 for models tested with randomly excluded data and 0.77, 0.83 and 0.78 for models tested with data from new hurricane events were obtained. This indicates a good performance if test data from the same event is used and slightly worse results for unknown hurricane events. Class-related patterns for precision and recall can be observed with respect to the data used for testing. Whereas the pattern is similar as described for flood models, a difference is observed for testing local models with new events, i.e., a lower precision and higher recall for *related*.

For the global models tested with unseen event data (figures 2d and 3d, table 2), the same pattern with lower precision and higher recall for *related* can be observed. This means that we can expect more false negatives and fewer false positives. A reason for this similar trend in both global models might be the fact that training is done using a large set of tweets from various event types, where only a very small fraction (a single new event) is used for testing. As expected and similar to results, for example reported in (Imran, Elbassuoni, et al. 2013; Win and Aung 2017), a drop of accuracies in case of new events can be observed. However, F1-scores between 0.81 and 0.86 indicate good accuracy compared to our baseline. Note that the scores discussed here were not obtained by testing with data excluded during CV, but by using data from completely different events. With respect to the 92 %

inter-annotator agreement reported in (Stowe et al. 2018), these results are quite satisfactory, even though higher performance variations can be expected with increasing event complexity.

Hypothetically, the application of local models to data from other event types should result in lower scores. The results in table 3 partially show a different behavior. Applying flood models to hurricane data results in 0.49 recall for *related*, indicating a higher complexity of hurricane events covering various sub-events. On the other hand, a high recall of around 0.78 in case of hurricane models applied on flood data reflects the fact that floods are sub-events of hurricanes. We therefore apply a global model trained with our proposed balanced data set to the Florence data.

Regarding the Florence data, we investigate whether our global models tend to provide the same accuracies as reported in the preceding experiments. According to figures 2d and 3d and table 2, we expect more false negatives than false positives as well as F1-scores of 0.80 ± 0.19 and better. This should result in a high percentage of correctly classified *unrelated* tweets. The $\sim 502,000$ tweets recorded during Hurricane florence that are classified as *unrelated* are therefore quantitatively analyzed by searching for crisis-related keywords (e.g. flood, hurricane, thunderstorm, tornado, and florence), as well as by manually evaluating random samples. A small fraction of $\sim 10,000$ wrongly classified tweets identified with this approach provides a hint that the model tends to behave as expected. A further indicator for this is the observation of a significantly higher percentage of *unrelated* tweets misclassified as *related*. A thorough review of randomly sampled tweets classified as *related* indicates a strong relationship between the CNN softmax outputs and misclassifications. In case of softmax values between $0.6 - 1.0$, the percentage of wrong classifications seems to be low and increases with decreasing softmax values below 0.6. The results obtained for the second data set from 2019 provide further evidence for these trends.

CONCLUSIONS AND OUTLOOK

In this work, the task of filtering crisis-related tweets is investigated. A strong dependency on chosen keywords for filtering motivates an approach for analyzing full tweet content with CNNs. Since this is intended to be the first analysis step for several crisis-related applications, a binary classification (*related* vs. *unrelated*) is used here.

In order to cover a broad range of different crisis event types as well as to overcome the often-observed problem of imbalanced training data, a new data set is compiled based on existing sets. Compared to other works, in which the same CNN was utilized, we obtain robust and even better results. In terms of model transferability to six flood and five hurricane events, our event-specific models are able to obtain F1-scores of $0.75 - 0.90$. However, since the usage of models for single event types may be ambiguous in case of similar events (e.g. floods often occur during hurricanes), we recommend to use models covering a broad range of event types. For new hurricane and flood events, an average F1-score of 0.83 ± 0.13 is obtained for these models.

However, our main focus is the application of models to real data streams. We are therefore currently investigating if the model behavior for data representing a realistic Twitter stream is similar to our experimental results reported in this work. First qualitative results with with a data set recorded during hurricane Florence indicate strong similarities. For a non-crisis period, only 8.3 % of all tweets were classified as *related*, further confirming the promising results.

In future works, we plan to (partially) label the Florence data set for further quantitative analyses. With the goal of model enhancement in case of new events, methods for domain adaptation, such as those proposed by (Li et al. 2018) for NB classifiers or online deep learning as proposed in (Nguyen, Joty, et al. 2016) could be further investigated.

REFERENCES

Alam, F., Ofli, F., and Imran, M. (2018). "CrisisMMD: Multimodal Twitter Datasets from Natural Disasters". In: *Proceedings of the 12th International AAAI Conference on Web and Social Media (ICWSM)*. Stanford, CA, USA.

Burel, G. and Alani, H. (May 2018). "Crisis Event Extraction Service (CREES) - Automatic Detection and Classification of Crisis-related Content on Social Media". In: *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*, p. 12.

Burel, G., Saif, H., Fernandez, M., and Alani, H. (May 2017). "On Semantics and Deep Learning for Event Detection in Crisis Situations". In: *Workshop on Semantic Deep Learning (SemDeep), at ESWC 2017*.

Burton, S. H., Tanner, K. W., Giraud-Carrier, C. G., West, J. H., and Barnes, M. D. (2012). "'Right Time, Right Place' Health Communication on Twitter: Value and Accuracy of Location Information". In: *Journal of Medical Internet Research* 14.6:e156.

Google Maps (2018). *V 7.3.2.5495, North Carolina, USA, lat 35.25, lon -78.91, eye alt 705 feet. SIO, NOAA, U.S. Navy, NGA, GEBCO. Landsat, Copernicus, Google 2018, accessed at December 19, 2018*.

Gruender-Fahrer, S., Schlaf, A., Wiedemann, G., and Heyer, G. (2018). "Topics and topical phases in German social media communication during a disaster". In: *Natural Language Engineering* 24.02, pp. 221–264.

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., and Meier, P. (2013). "Practical extraction of disaster-relevant information from social media". In: *Proceedings of the 22nd International Conference on World Wide Web (WWW) Companion*. Rio de Janeiro, Brazil: ACM Press, pp. 1021–1024.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015). "Processing Social Media Messages in Mass Emergency: A Survey". In: *ACM Computing Surveys* 47.4, pp. 1–38.

Imran, M., Mitra, P., and Castillo, C. (May 2016). "Twitter as a Lifeline: Human-annotated Twitter Corpora for NLP of Crisis-related Messages". In: *Proceedings of the 10th International Conference on Language Resources and Evaluation (LREC)*. Portoroz, Slovenia: European Language Resources Association (ELRA).

Kim, Y. (2014). "Convolutional Neural Networks for Sentence Classification". In: *Proceedings of the Conference on Empirical Methods in Natural Language Processing, EMNLP 2014, October 25-29, Doha, Qatar, A meeting of SIGDAT, a Special Interest Group of the ACL*, pp. 1746–1751.

Kumar, S., Barbier, G., Abbasi, M. A., and Liu, H. (2011). "TweetTracker: An Analysis Tool for Humanitarian and Disaster Relief". In: *Proceedings of the 5th International AAAI Conference an Weblogs Social Media (ICWSM)*, pp. 661–662.

Landwehr, P. M. and Carley, K. M. (2014). "Social Media in Disaster Relief - Usage Patterns, Data Mining Tools, and Current Research Directions". In: *Data Mining and Knowledge Discovery for Big Data*. Ed. by W. W. Chu. Vol. 1. Berlin, Heidelberg: Springer, pp. 225–257.

Li, H., Caragea, D., Caragea, C., and Herndon, N. (Mar. 2018). "Disaster response aided by tweet classification with a domain adaptation approach". In: *Journal of Contingencies and Crisis Management* 26.1, pp. 16–27.

McMinn, A. J., Moshfeghi, Y., and Jose, J. M. (2013). "Building a Large-scale Corpus for Evaluating Event Detection on Twitter". In: *Proceedings of the 22nd ACM International Conference on Information & Knowledge Management (CIKM)*. San Francisco, California, USA: ACM, pp. 409–418.

Mikolov, T., Chen, K., Corrado, G., and Dean, J. (2013). "Efficient Estimation of Word Representations in Vector Space". In: *CoRR* abs/1301.3781. arXiv: 1301.3781.

NASA Earth Observatory (2018). https://earthobservatory.nasa.gov/images/92775/florence-inundates-the-carolinas, accessed: December 19, 2018.

Nguyen, T. D., Al-Mannai, K. A., Joty, S., Sajjad, H., Imran, M., and Mitra, P. (Jan. 2017). "Robust classification of crisis-related data on social networks using convolutional neural networks". In: *Proceedings of the 11th International Conference on Web and Social Media (ICWSM)*. AAAI press, pp. 632–635.

Nguyen, T. D., Joty, S. R., Imran, M., Sajjad, H., and Mitra, P. (2016). "Applications of Online Deep Learning for Crisis Response Using Social Media Information". In: *CoRR* abs/1610.01030.

Olteanu, A., Castillo, C., Diaz, F., and Vieweg, S. (2014). "CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises". In: *Proceedings of the 8th International AAAI Conference on Web and Social Media*.

Olteanu, A., Vieweg, S., and Castillo, C. (2015). "What to Expect When the Unexpected Happens: Social Media Communications Across Crises". In: *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*. Vancouver, BC, Canada: ACM, pp. 994–1009.

Parilla-Ferrer, B. E., Fernandez, P., and T. Ballena IV, J. (Dec. 2014). "Automatic Classification of Disaster-Related Tweets". In: *International conference on Innovative Engineering Technologies (ICIET)*. Bangkok, Thailand.

Periñán-Pascual, C. and Arcas-Túnez, F. (June 2018). "The Analysis of Tweets to Detect Natural Hazards". In: *Intelligent Environments 2018 - Workshop Proceedings of the 14th International Conference on Intelligent Environments (IE), Rome, Italy, 25-28 June 2018*, pp. 87–96.

Ramachandran, D. and Ramasubramanian, P. (2018). "Event detection from Twitter - a survey". In: *Int. J. of Web Information Systems* 14.3, pp. 262–280.

Reuter, C. and Kaufhold, M.-A. (2018). "Fifteen years of social media in emergencies: A retrospective review and future directions for crisis Informatics". In: *Journal of Contingencies and Crisis Management* 26.1, pp. 41–57.

Stieglitz, S., Mirbabaie, M., Ross, B., and Neuberger, C. (2018). "Social media analytics - Challenges in topic discovery, data collection, and data preparation". In: *Int. J. of Information Management* 39, pp. 156–168.

Stowe, K., Palmer, M., Anderson, J., Kogan, M., Palen, L., Anderson, K. M., Morss, R., Demuth, J., and Lazrus, H. (2018). "Developing and Evaluating Annotation Procedures for Twitter Data during Hazard Events". In: *Proceedings of the Joint Workshop on Linguistic Annotation, Multiword Expressions and Constructions (LAW-MWE-CxG-2018)*. Santa Fe, New Mexico, USA: Association for Computational Linguistics, pp. 133–143.

Win, S. S. M. and Aung, T. N. (May 2017). "Target oriented tweets monitoring system during natural disasters". In: *Proceedings of the IEEE/ACIS 16th International Conference on Computer and Information Science (ICIS)*, pp. 143–148.

Detecting Event-Related Tweets by Example using Few-Shot Models

Anna Kruspe*
German Aerospace Center (DLR)
Jena, Germany
anna.kruspe@dlr.de

Jens Kersten
German Aerospace Center (DLR)
Jena, Germany
jens.kersten@dlr.de

Friederike Klan
German Aerospace Center (DLR)
Jena, Germany
friederike.klan@dlr.de

ABSTRACT

Social media sources can be helpful in crisis situations, but discovering relevant messages is not trivial. Methods have so far focused on universal detection models for all kinds of crises or for certain crisis types (e.g. floods). Event-specific models could implement a more focused search area, but collecting data and training new models for a crisis that is already in progress is costly and may take too much time for a prompt response. As a compromise, manually collecting a small amount of example messages is feasible. Few-shot models can generalize to unseen classes with such a small handful of examples, and do not need be trained anew for each event. We show how these models can be used to detect crisis-relevant tweets during new events with just 10 to 100 examples and counterexamples. We also propose a new type of few-shot model that does not require counterexamples.

Keywords

Social media, Twitter, Relevance, Keywords, Hashtags, Few-shot models, One-class classification

INTRODUCTION

Social media is an interesting source of information during disasters that has become a topic of research in recent years. Twitter users, as an example, write about disaster preparations, developments, recovery, and a host of other topics (Niles et al. 2018). Retrieving this information could lead to significant improvements in disaster management strategies. According to a Red Cross study, 69% of Americans think that emergency response agencies should respond to calls for help sent through social media channels (American Red Cross 2010). The crux of this matter lies in the retrieval and classification of such messages. Twitter users generate 5,800 tweets per second on average[1]. Even with hashtag- or location-based pre-filtering, sophisticated automatic methods are necessary to detect disaster-related messages in acceptable timespans. Approaches published so far have mainly had the generalized detection of any disaster-related tweet as their objective (Burel and Alani 2018), or have focused on specific types of disasters (Caragea et al. 2016). Designing models specific to a certain event could potentially yield much more exact results, but training such dedicated models would require large amounts of already available data and take up critical time in a disaster.

In this paper, we present a first approach that facilitates the detection of Twitter messages (tweets) pertaining to a specific event on the basis of example tweets. These models can be trained well in advance, and then require as few as ten examples against which new tweets are compared. We test few-shot networks that either require both "pro" examples and counterexamples of the event, and a new type that only requires "pro" examples. These approaches obtain F_1 meaures of 75 – 76% on tweets from unseen events opposed to tweets from other events. The paper is

*corresponding author
[1] https://www.omnicoreagency.com/twitter-statistics/

organized as follows: In the next two sections, we will present an overview of related work and the data sets used in our experiments. The sections afterwards describe the proposed approaches and our experimental results. In the last section, we give a conclusion of our work so far and make suggestions for future experiments.

RELATED WORK

As described above, users generate huge amounts of data on Twitter every second, and finding tweets related to an ongoing event is not trivial (Landwehr and Carley 2014). Several detection approaches have been presented in literature so far.

The most obvious strategy is the filtering of tweets by various surface characteristics as shown in (Kumar et al. 2011), for example. Keywords and hashtags are used most frequently for this and often serve as a useful pre-filter. Olteanu et al. developed a lexicon called *CrisisLex* for this purpose (Olteanu, Castillo, et al. 2014). However, this approach easily misses tweets that do not mention the keywords specified in advance, particularly when changes occur or the attention focus shifts during the event. It may also retrieve unrelated data that contains the same keywords (Imran, Castillo, et al. 2015). Geo-location is another frequently employed feature that can be useful for retrieving tweets from an area affected by a disaster. However, this approach misses important information that could be coming from a source outside the area, such as help providers or news sources. Additionally, only a small fraction of tweets is geo-tagged at all, leading to a large amount of missed tweets from the area (Sloan et al. 2013). To resolve these problems, several other strategies were developed, starting with crowdsourcing platforms. On these platforms, a large amount of users hand-selects and labels incoming tweets in disaster situations. Examples include *Ushahidi*[2] and *CrisisTracker* (Rogstadius et al. 2013). Some of them already integrate "traditional" machine learning models, e.g. *AIDR* (Imran, Castillo, et al. 2015).

In recent years, approaches based on deep learning techniques have come to the forefront of research. On a more general level, the problem falls under the umbrella of event detection as shown, for example, in (Chen et al. 2015; Feng et al. 2016; T. H. Nguyen and Grishman 2015). Caragea et al. first employed Convolutional Neural Networks (CNN) for the classification of tweets into those related to flood events and those unrelated (Caragea et al. 2016). In many of the following approaches, a type of CNN developed by Kim for text classification is used (Kim 2014), such as in (Burel and Alani 2018). This method achieves an accuracy of 80% for the classification into related and unrelated tweets. In the same publication as well as in (Burel, Saif, et al. 2017) and (D. T. Nguyen et al. 2016), this kind of model is also used for information type classification. For comparison purposes, we also tested the relatedness model from (Burel and Alani 2018) on our test data set (*CrisisNLP*, see below) and obtained an F_1 measure of .86 and an accuracy of .77, although the data in this case is strongly unbalanced as there are few tweets in that data set that do not belong to any crisis.

All of these approaches aim to generalize to any kind of event without any *a priori* information. A real-world system may not need to be restricted in this way; in many cases, its users will already have some information about the event, and may already have spotted tweets of the required type. This removes the need to anticipate any type of event. It also directs the system towards a specific event rather than any event happening at that time. Alam et al. (Alam et al. 2018) propose an interesting solution to this: Their system includes an adversarial component which can be used to adapt a model trained on a specific event to a new one (i.e. a new domain).

We propose a system that does not assume an explicit notion of relatedness vs. unrelatedness (or relevance vs. irrelevance) to a crisis event. These qualities are not easy to define, and might vary for different users or different types of events. Additionally, as in (Alam et al. 2018), we are interested in a method that is specific to an event rather than attempting to detect any kind of crisis-related tweet. In this paper, we demonstrate how to implement a system that is able to determine whether a tweet belongs to a class (i.e. crisis event) implicitly defined by a small selection of example tweets. We employ few-shot models to for this purpose; an overview over work related to this topic is given later.

DATA

We employ two widely-used collections of disaster-related tweets to train and test our models: *CrisisLexT26* and *CrisisNLP*.

[2] https://www.ushahidi.com/

Event	Hashtag	Occurrences/1001
2012 Typhoon Pablo	#PabloPH	453
2013 Bohol Earthquake	#PrayForVisayas	338
2013 Singapore Haze	#sghaze	667
2013 West Texas Explosion	#PrayForTexas	152
2012 Italy Earthquakes	#terremoto	711
2013 Manila Floods	#MaringPH	399
2013 Boston Bombings	#PrayForBoston	259
2013 Brazil Nightclub Fire	#SantaMaria	353
2013 Colorado Floods	#coflood	317
2013 LA Airport Shootings	#LAX	451
2012 Guatemala Earthquake	#sismo	165
2012 Philippines Floods	#rescuePH	571
2013 Sardinia Floods	#Sardegna	764
2012 Venezuela Refinery Explosion	#Amuay	588
2013 Alberta Floods	#yycflood	497
2013 Lac Megantic Train Crash	#LacMegantic	254
2013 Typhoon Yolanda	#Haiyan	264
2013 Glasgow Helicopter Crash	#Clutha	286
2013 Queensland Floods	#bigwet	684
2012 Colorado Wildfires	#colorado	151
2013 Australia Bushfire	#nswfires	481
2013 Savar Building Collapse	#Bangladesh	579
2012 Costa Rica Earthquake	#earthquake	363
2013 Russia Meteor	#RussianMeteor	407

Table 1. Hashtags chosen for the *CrisisLexT26* data set. (Two events did not contain frequent hashtags and were therefore excluded.)

CrisisLexT26

CrisisLex was first published by Olteanu et al. in 2014 (Olteanu, Castillo, et al. 2014) and expanded later to *CrisisLexT26* (Olteanu, Vieweg, et al. 2015). It contains tweets collected during 26 crises, mainly natural disasters like earthquakes, wildfires and floods, but also human-induced disasters like shootings and a train crash. Amounts of these tweets per disaster range between 1,100 and 157,500. In total, around 285,000 tweets were collected. They were then annotated by paid workers on the *CrowdFlower* crowdsourcing platform[3] according to three concepts: Informativeness, information type, and tweet source. In this work, a balanced set containing 1,100 English-language tweets per event is used. Two events were excluded as no frequent hashtags for them were found (see below).

CrisisNLP

Similar to *CrisisLexT26*, the team behind *CrisisNLP* collected tweets during 19 natural and health-related disasters and published them for research (Imran, Mitra, et al. 2016). Collected tweets range between 17,000 and 28 million per event, making up around 53 million in total. Out of these, around 50,000 were annotated both by volunteers and by paid workers on *CrowdFlower* with regard to information type. In this work, only the tweets with *CrowdFlower* annotations were utilized. These tweets come from a subset of 11 English-language event sets, summing up to around 23,000 in total. There is no overlap between the events in both data sets.

Experimental data composition

In order to train and test our few-shot models, sub-sets of positive and negative supports for a class (examples and counterexamples) plus an either positive or negative query are necessary. As an example from a different domain, a positive support set for cat classification may consist of a number if images showing cats, while the negative support set may show other animals or completely different content. Analogously, positive and negative queries would consist of unseen images of cats or other animals respectively.

In few-shot models, training steps performed on such sets are called “episodes”. For our purposes, tweets are considered to belong to the same class if they are associated with the same event. The annotations provided with the *CrisisLexT26* and *CrisisNLP* data sets are not used, apart from filtering out tweets that were tagged as unrelated or irrelevant. Event selection for each episode is performed in such a way that all events are equally likely. To generate

[3]Now named *Figure Eight*, https://www.figure-eight.com/

Event	Hashtag	Occurrences/Total
2013 Pakistan Earthquake	#Balochistan	402/2015
2014 California Earthquake	#napa	272/2016
2014 Chile Earthquake	#PrayForChile	452/2014
2014 Ebola Virus	#ebola	999/2018
2014 Hurricane Odile	#Odile	440/2016
2014 India Floods	#india	250/2009
2014 MERS	#MERS	589/2021
2014 Pakistan Floods	#KashmirFloods	218/2016
2014 Typhoon Hagupit	#hagupit	439/2016
2015 Cyclone Pam	#vanuatu	336/2014
2015 Nepal Earthquake	#NepalQuake	309/3022

Table 2. Hashtags chosen for the *CrisisNLP* data set.

episode data packs, tweets for an event containing a specific hashtag are selected randomly to create the positive support set. Upper- and lower-case versions are equalized, and this hashtag is removed in a pre-processing step so as not to bias the classifier towards it. For positive queries, tweets without the hashtag, but coming from the same event are picked randomly. For negative supports and queries, random tweets from other events are used. Hashtags were chosen manually according to their prevalence in the event's tweets. An overview is given in tables 1 and 2. The practical reasoning for this is that during an ongoing event, a user could quickly search for example tweets by a certain hashtag, then use the found examples to detect more event-related tweets without this hashtag using the models proposed by us. (Of course, a user may just as well use any other method for selecting examples of the class they are interested in).

In the few-shot experiments, *CrisisLexT26* is used to generate the training episodes, and *CrisisNLP* is used for the validation episodes. In this way, we ensure that our results represent the generalization ability of the models rather than their ability to adapt to a set of specific events.

PROPOSED APPROACHES

We propose three approaches for detecting event-related tweets. In the first approach, we train models explicitly on tweets related to one single event, then use these models to determine whether other tweets also belong to this event or a different one. The second and third approach both focus on few-shot models, meaning that we train models to determine whether unseen tweets belong to the same event as a small number of support examples specified at testing time (instead of training time). This means that models are also able to perform this distinction for events not seen in the training data, providing a flexible method for detecting related tweets during a new event. The difference between the second and third approach lies in the concrete employed methods. In the second approach, we train matching networks, one of the first types of few-shot-models proposed. For classification by event-relatedness, such models require both positive support examples (i.e. belonging to the event) and negative ones. In the third approach, we go one step further by training a new type of few-shot model that only requires positive support examples, so-called one-way prototypical networks.

Dedicated event models

As an anchor experiment, we trained event-wise models directly on all tweets containing the event-related hashtag plus random tweets from other events. We then tested them on tweets from the same event without the hashtag, and random tweets from other events.

The architecture used in this experiment is a Convolutional Neural Network (CNN) as proposed by Kim (Kim 2014). A visualization is provided in figure 1. This approach was originally developed for classifying sentences into semantic categories, e.g. question types or sentiments. In a pre-processing step, each tweet is padded with empty units or shortened to contain exactly 25 words. At the input, these words are transformed into word embeddings using pre-trained weights, which we keep static througout training. We use the pre-trained, crisis-specific *word2vec* embeddings described in (D. T. Nguyen et al. 2016). Then, several convolutional layers with different kernel widths are applied in parallel. Global max-pooling is performed for each of these layers, and the results are concatenated. This new embedding is then fed into a 128-dimensional fully connected layer with dropout and a subsequent softmax layer to determine the final class. We set all hyperparameters as suggested by Kim. This type of model has successfully been used for crisis-related data (Burel and Alani 2018; D. T. Nguyen et al. 2016).

We expect these models to perform very well as they are dedicatedly adapted to a certain event. However, this is almost never an option in a real-world situation because it would require the collection of a large amount of related data in advance, which is not possible until social media users have been discussing the event to some extent. Additionally, a new model has to be trained from scratch (or at least finetuned from a generic model), which uses up even more valuable time during an event. The resulting model is also not very flexible; if discussion topics within the event shift, it may not perform well anymore. For these reasons, this experiment serves merely as an upper boundary for the accuracy of a model trained on event-specific hashtags.

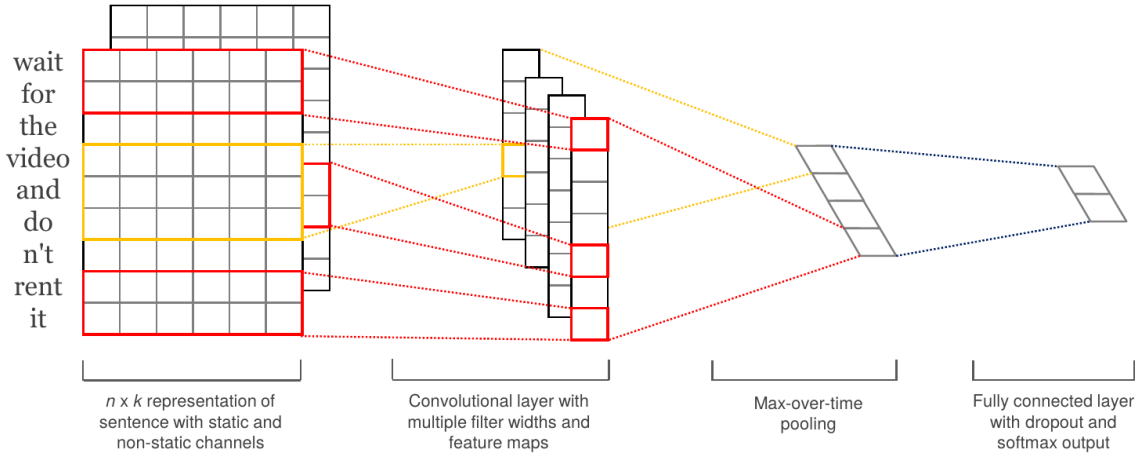


Figure 1. CNN for text classification as proposed by Kim (Kim 2014).

Matching networks for few-shot learning

Matching networks which implement one-shot learning were first introduced by Vinyals et al. in 2016 (Vinyals et al. 2016). The concept of one- or few-shot learning is motivated by human learning: If human subjects are presented with examples of a new class of objects, they usually only require very few to be able to match new instances to this class (e.g. when children are shown an animal not encountered before). This ability is, among other factors, informed by general world experience, which teaches humans to set boundaries between object classes. Matching networks are thus trained on sets of support examples for a subset of possible classes plus a query example belonging to one of the classes in so-called episodes. These episodes are generated for a wide range of class permutations. In the one-shot case, only one support example is given for each class, while there are multiple ones in few-shot models.

An example of the basic structure of one-shot matching networks is shown in figure 2. The network has two input branches: One for the support examples, and one for the query example. In both branches, the inputs are run through a sub-network which performs an embedding (expressed as embedding functions g and f). The embedding networks may or may not share their weights. The query's resulting embedding is then compared against the supports' resulting embeddings using a pre-defined distance metric. This results in likelihood measures for each input class, commonly implemented with a softmax. The over-all comparison metric for the task is learned implicitly as the network learns an appropriate embedding.

In the few-shot case, multiple support examples per class are treated independently of each other throughout the network. Example-related likelihoods are then summed into class likelihoods at the output. In this way, matching networks essentially implement a weighted nearest-neigbor classification. Few-shot learning has been used for short-text classification in (Yan et al. 2018). The architecture is slightly different, employing a CNN-based Siamese network with hinge loss as the distance metric and a subsequent SVM classifier. Support examples for one class are combined into a prototype (also see next section). The approach is tested for sentiment classification of tweets, among other tasks, where it outperforms other deep learning models.

For our experiments, we employ a relatively straightforward matching network architecture, which is illustrated in figure 3. The network has one input branch for a number of support examples for each class, and another for one query example. The subsequent CNN is identical to the one described in the previous section with all hyperparameters set to Kim's suggestions, except that there is only one 512-dimensional fully connected layer

without a softmax function after the max-pooling layers. Its outputs are used as the internal embeddings in the further processing. They are fed into a distance metric layer, where the query embedding is compared to each support embedding. As proposed in (Vinyals et al. 2016), we use the cosine distance as our metric here. The resulting distances are then processed by a softmax layer and summed up for each class, generating the final class scores.

Because we are applying matching networks to a binary problem (a query tweet is either related the considered event or not), we need support examples for two classes: Positive examples of tweets concerning the event, and random other tweets. Semantically, this amounts to a workaround, as there are no two comparable classes. Instead, one of them merely consists of counterexamples (a sort of "garbage" class). Examples in this class will have a much wider feature distribution. This makes selecting random examples difficult, as they should still be representative of this distribution, particularly when only a small number of support examples is used.

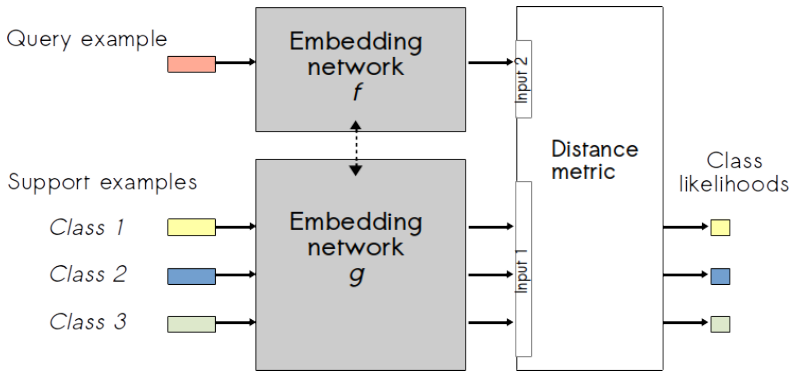


Figure 2. Matching network architecture as proposed by Vinyals et al. (Vinyals et al. 2016).

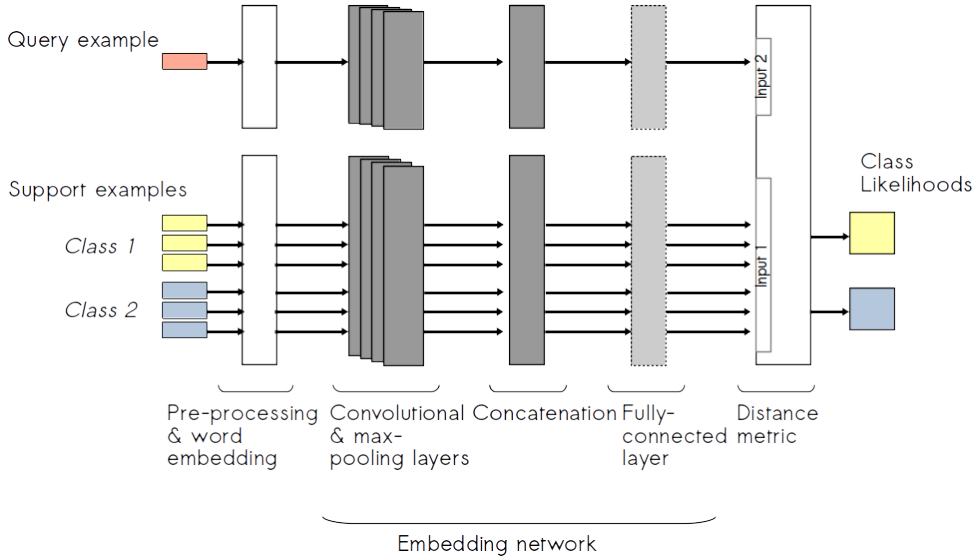


Figure 3. Matching network architecture used in our experiments.

One-way prototypical networks for few-shot learning

Prototypical networks are an extension to matching networks and were proposed by Snell et al. in 2017 (Snell et al. 2017). Instead of treating all of a class' support examples independently in the few-shot case, they compute a so-called "prototype" of the class after the embedding network. This prototype is commonly the mean of the class; a visualization is provided in figure 5. When the squared Euclidean distance is used as the metric, this implements a linear classifier (as opposed to the nearest neighbor classifier produced by matching networks).

We take this approach one step further. As described above, using counterexamples as one class in a binary few-shot problem presents some difficulties. We therefore construct a prototypical network that only requires positive support examples, from which it generates an internal embedding of the whole class. The query embedding is then compared

to this, and judged to belong to the same class or not. We call this type of network a "one-way prototypical network". The sub-network for generating the internal embeddings is the same as before. An illustration is shown in figure 4.

This approach presents a challenge for the distance metric: Because Cosine or Euclidean distances are not bounded, we cannot set a threshold for class belonging. We solve this by substituting a novel Gaussian probability layer. In this layer, Gaussian distributions are fitted over the support embeddings for each embedding dimension. Then, the probability of each of the query embedding's dimensions is calculated and normalized. The average of these probabilities is used as the final result, i.e. the likelihood of the query belonging to the supported class.

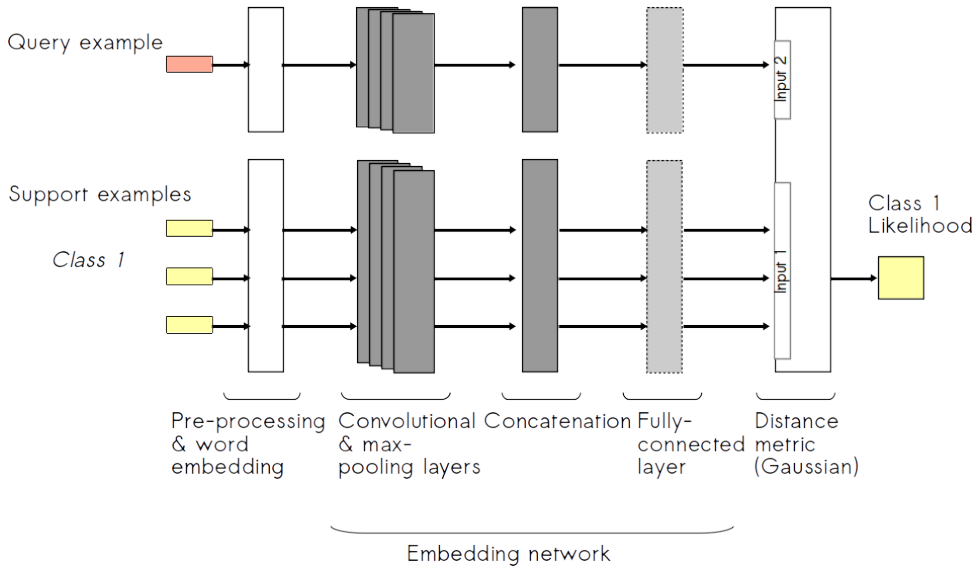


Figure 4. One-way prototypical network architecture used in our experiments.

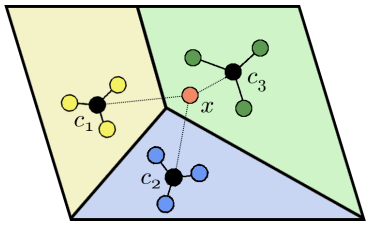


Figure 5. Calculation of class prototypes c_k by averaging support embeddings as proposed by Snell et al. (Snell et al. 2017).

EXPERIMENTAL RESULTS

In this section, we present the experimental set-ups and results for each of the three proposed approaches.

Dedicated event models

As described in the previous section, we start by training dedicated models for each event in the *CrisisLexT26* data set. Training is performed on tweets containing the matching hashtag from table 1 and unrelated examples from other events. The models are then tested on tweets from the considered event without the hasthtag.

The results are shown in figure 6. As expected, training individual models on the data specific to an event works very well due to the focus on a small set of topics or keywords. F_1 measures range between .8 and 1, with an average of .94. Events of types that occur multiple times in the data set produce somewhat lower values (e.g. floods, earthquakes), suggesting at least a partial focus of the model on the event type rather than the specific event. This is to be expected and not necessarily a problem for practical purposes, unless two events of the same type occur at the same time. Other influences may include the use of other languages than English in the event data, and the range of topics of interest during an event, which is also related to the duration of the event.

At first glance, these results appear higher than the state of the art; however, we are aiming for a different goal here. Due to a training strategy that is specific to certain events, models are able to develop a very narrow focus. We also

do not classify tweets with regard to their relevance or general event-relatedness, but rather by their relatedness to a specific event (with negative examples being tweets from other events). As such, the results are not directly comparable to the state of the art. Despite the high F_1 measures achieved with dedicated models, this approach will often be infeasible during an actual event. A significant amount of data for the event needs to be collected first, and then model training has to be performed and optimized. This strategy could be implemented for events that unfold over a longer timespan; however, this introduces the problem of shifting topics during the course of the event, for which the model may not be well-adapted anymore.

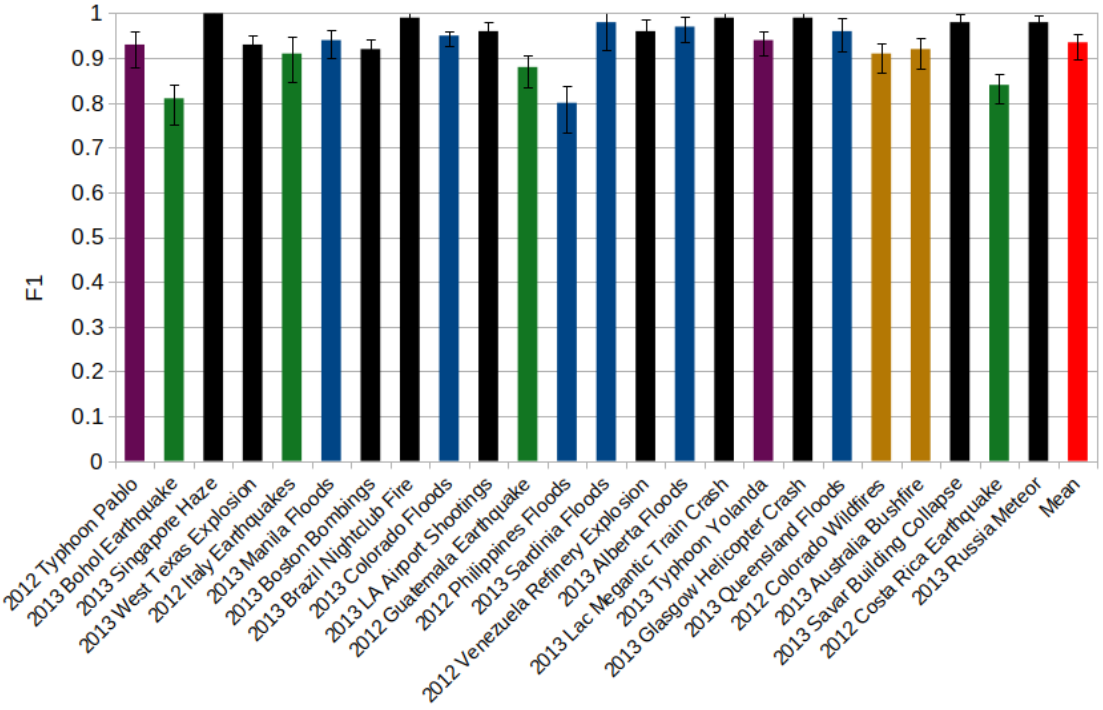


Figure 6. Results of the dedicated event model experiments. F_1 is shown for each individual event; the last bar is the mean. Colors correspond to types of events (black bars do not belong to a repeated type).

Matching networks

In our second set of experiments, we train matching networks. Training episodes are generated from random tweets from *CrisisLexT26* containing the matching hashtag from table 1 as the positive supporting examples, and random tweets from other events as the negative ones; queries are generated from event-related tweets without the hashtag, and once again random tweets from other events. This model is then evaluated on the *CrisisNLP* data set, where test episodes are generated in the same way. Positive and negative queries are selected with the same likelihood, resulting in a 50%/50% distribution for the two classes.

The results are shown in figure 7. In total, 40 configurations are tested: Training is performed with 1,280 to 12,800 episodes (colored bars), and the number of support examples per class is varied between 10 and 100. Testing is performed on 12,800 episodes in each configuration. As a general tendency, F_1 improves with more support examples and with more training episodes. However, as few as 20 support examples already produce an F_1 of .74 when trained on a sufficient number of episodes. The results become slightly higher up to 80 or 90 support examples. Providing more support examples improves the likelihood that a query tweet will be similar to one of the support examples. In our use case, the main difficulty for this lies in the negative queries, as those will be very diverse, just as the negative support examples. Considering the amount of training episodes, F_1 does not improve much beyond 6400. At this point, many of the possible permutations may already be covered in the randomly generated episodes. Further episodes then do not provide more information and just serve to effectively increase the number of training epochs. Of course, this is dependent on the size of the data set.

Over-all, the results do not vary highly across parameter configurations, and their tendencies are somewhat noisy. We believe that this has to do with the random creation of the episodes, especially with regards to negative examples. However, at a top F_1 of .76 on completely unseen events, this approach is feasible for use in a real-world system for

the detection of event-related tweets. With no necessary re-training, the model can be used out-of-the-box for new events. The result is somewhat lower than that of the state of the art for detecting related tweets (F_1 of .86 with the model from (Burel and Alani 2018)); however, our approach is specific to a certain event versus other events instead of a classification of general event-relatedness.

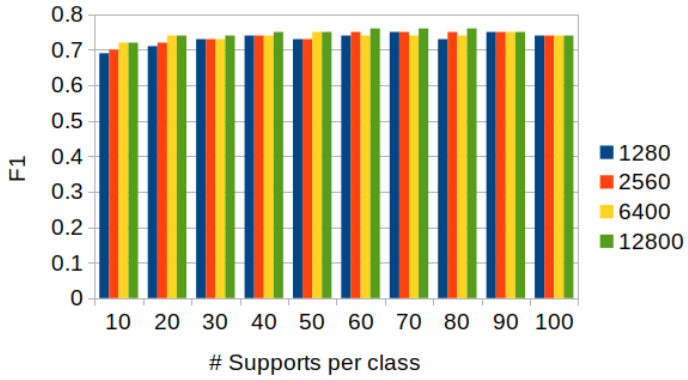


Figure 7. Results of the matching network experiments in terms of F_1 vs. number of support examples per class; colored bars represent the number of training episodes.

One-way prototypical networks

Finally, we perform experiments with one-way prototypical networks on the same data. As described above, these networks only require positive examples for the considered event, removing the issue of choosing a representative set of counterexamples. Once again, models are trained on 1,280 to 12,800 automatically generated episodes with 10 to 100 support examples for the one class, and tested on 12,800 episodes. Figure 8 shows the results.

The best achieved F_1 is 75%, demonstrating that this new type of network works just as well for our purposes as the previously existing matching networks. The trends are the same as in the previous experiment: More training episodes generally improve F_1, although further experiments show that this effect diminishes beyond 12,800. More support examples also help, but this does not change much between 40 and 100. Since this type of model calculates a Gaussian distribution on the support examples' internal embeddings, we assume that these distributions can be estimated well enough from 40 examples or even fewer. One effect that stands out is that these trends are much clearer here. This is probably the case because of the non-reliance on counterexamples. These introduce noise to the process, which might make the model work better or worse in some cases because of the selection of these examples and their distribution and relation to the positive examples.

Just like the previously analyzed matching network models, this method is well-suited for practical operation as no re-training is necessary for a new event. In contrast to the previous approach, only half as many support examples need to be collected, and no attention has to be paid to finding widely distributed counterexamples. In an additional experiment (not shown here), we also tried using tweets not related to any disaster as the negative queries, as opposed to training against negative queries from other disasters. This approach achieves an accuracy of around .8, which is around the state of the art for the relatedness task (Burel and Alani 2018). In many practical cases, this model will be sufficient, as users will often not need to distinguish events from each other if there is only one happening at that time. Despite some thematic overlap, this model will still be more focused on the event for which support examples are given rather than all events.

CONCLUSION & FUTURE WORK

In this paper, we demonstrate three approaches for detecting tweets related to a specific crisis. In the first one, we train dedicated models for this crisis. This results in a mean F_1 of .94. For the second experiment, we train matching networks for sets of 10 to 100 support examples and counterexamples for the considered event. We then develop this approach further by training one-way prototypical networks, which do not require counterexamples anymore. The second and third method produce F_1 measures of .76 and .75 respectively.

All three approaches are good enough to potentially be used as a filtering mechanism in crisis situations. However, training dedicated crisis models will often be infeasible as this takes up too much time and effort for a quick response. Both of the other approaches can be used out-of-the-box in a new scenario, only requiring some example tweets. As

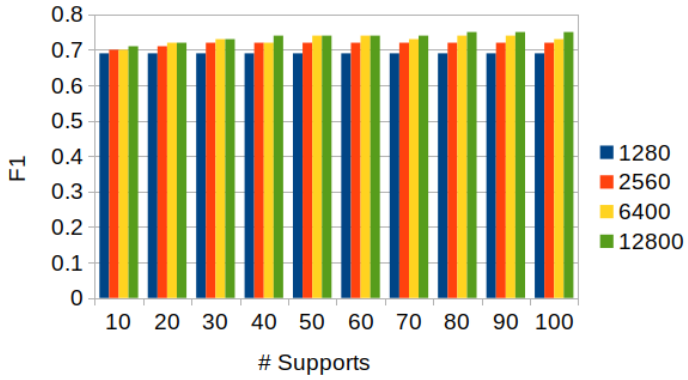


Figure 8. Results of the one-way prototypical network experiments in terms of F_1 vs. number of support examples per class; colored bars represent the number of training episodes.

the results produced by the matching network show, the selection of the counterexamples can have an effect on the over-all effectiveness of the model, depending on their variation and relatedness to the positive examples. The one-way prototypical network removes this issue and is therefore even easier to integrate into a live system.

Our experiments on the matching networks and one-way prototypical networks show that the number of support examples and the number of training episodes have a small effect on the test accuracy. In the case of the support examples, this effect disappears beyond 40, probably because this amount of support examples already covers the semantic space well in many cases. For the number of training episodes, we also observed diminishing returns after a certain number because many permutations will already have occurred at that point.

Some easy adaptations could be made to the processing stages of these models for a real-world system. Depending on whether better precision or better recall is required, the decision boundary can be adjusted accordingly. When topics during the event shift, new support examples can be picked on-the-fly. This is particularly interesting for live streaming operation. We also performed additional experiments (not shown here) on the same systems trained on support data for various event versus non-event data. This improved the accuracy to around .80, and may often be more suitable for a practical system.

In the future, these methods could be improved in a number of ways. Ideally, they could be trained on a much wider range of (disaster) events as this would help their generalization abilities towards unseen events. When possible, the counterexamples could be picked in a more directed fashion to stabilize the networks' decision boundaries, or the network could simply be enabled to process a much larger amount of counterexamples than positive examples without changing the class priors. Finally, the one-way prototypical network method itself could be expanded in multiple ways, e.g. by replacing the Gaussian probability layer with a Gaussian Mixture Model (Kersten 2014).

REFERENCES

Alam, F., Joty, S., and Imran, M. (July 2018). "Domain Adaptation with Adversarial Training and Graph Embeddings". In: *56th Annual Meeting of the Association for Computational Linguistics (ACL)*. Melbourne, Australia.

American Red Cross (Aug. 2010). *Social Media in Disasters and Emergencies*.

Burel, G. and Alani, H. (May 2018). "Crisis Event Extraction Service (CREES) - Automatic Detection and Classification of Crisis-related Content on Social Media". In: *15th International Conference on Information Systems for Crisis Response and Management*. Rochester, NY, USA.

Burel, G., Saif, H., and Alani, H. (Oct. 2017). "Semantic Wide and Deep Learning for Detecting Crisis-Information Categories on Social Media". In: *International Semantic Web Conference (ISWC)*. Vienna, Austria.

Caragea, C., Silvescu, A., and Tapia, A. H. (May 2016). "Identifying informative messages in disaster events using Convolutional Neural Networks". In: *13th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*. Rio de Janeiro, Brazil.

Chen, Y., Xu, L., Liu, K., Zeng, D., and Zhao, J. (July 2015). "Event Extraction via Dynamic Multi-Pooling Convolutional Neural Networks". In: *53rd Annual Meeting of the Association for Computational Linguistics (ACL)*. Beijing, China.

Feng, X., Qin, B., and Liu, T. (Aug. 2016). "A language-independent neural network for event detection". In: *54th Annual Meeting of the Association for Computational Linguistics (ACL)*. Berlin, Germany.

Imran, M., Mitra, P., and Castillo, C. (May 2016). "Twitter as a lifeline: Human-annotated twitter corpora for NLP of crisis-related messages". In: *Tenth International Conference on Language Resources and Evaluation (LREC)*. Portoroz, Slovenia.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (June 2015). "Processing Social Media Messages in Mass Emergency: A Survey". en. In: *ACM Computing Surveys* 47.4, pp. 1–38.

Kersten, J. (Aug. 2014). "Simultaneous feature selection and Gaussian mixture model estimation for supervised classification problems". In: *Pattern Recognition* 47.8, pp. 2582–2595.

Kim, Y. (Oct. 2014). "Convolutional neural networks for sentence classification". In: *2014 Conference on Empirical Methods in Natural Language Processing (EMNLP)*. Doha, Qatar.

Kumar, S., Barbier, G., Abbasi, M. A., and Liu, H. (2011). "TweetTracker: An Analysis Tool for Humanitarian and Disaster Relief". In: *International AAAI Conference on Weblogs and Social Media (ICWSM)*.

Landwehr, P. M. and Carley, K. M. (Jan. 2014). "Social Media in Disaster Relief - Usage Patterns, Data Mining Tools, and Current Research Directions". In: *Data Mining and Knowledge Discovery for Big Data*. Ed. by W. W. Chu. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 225–257.

Nguyen, D. T., Joty, S. R., Imran, M., Sajjad, H., and Mitra, P. (Oct. 2016). "Applications of Online Deep Learning for Crisis Response Using Social Media Information". In: *International Workshop on Social Web for Disaster Management (SWDM)*. Los Angeles, CA, USA.

Nguyen, T. H. and Grishman, R. (July 2015). "Event Detection and Domain Adaptation with Convolutional Neural Networks". In: *53rd Annual Meeting of the Association for Computational Linguistics (ACL)*. Beijing, China.

Niles, M. T., Emery, B. F., Reagan, A. J., Dodds, P. S., and Danforth, C. M. (Oct. 2018). *Social media usage patterns during natural hazards*. eprint: arXiv:1806.07451.

Olteanu, A., Castillo, C., Diaz, F., and Vieweg, S. (June 2014). "CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises". In: *AAAI Conference on Weblogs and Social Media (ICWSM)*. Ann Arbor, MI, USA.

Olteanu, A., Vieweg, S., and Castillo, C. (Mar. 2015). "What to Expect When the Unexpected Happens: Social Media Communications Across Crises". In: *Conference on Computer Supported Cooperative Work and Social Computing (ACM CSCW)*. Vancouver, BC, Canada.

Rogstadius, J., Vukovic, M., Teixeira, C. A., Kostakos, V., Karapanos, E., and Laredo, J. A. (Sept. 2013). "CrisisTracker: Crowdsourced social media curation for disaster awareness". In: *IBM Journal of Research and Development* 57.5, 4:1–4:13.

Sloan, L., Morgan, J., Housley, W., Williams, M., Edwards, A., Burnap, P., and Rana, O. (Aug. 2013). "Knowing the Tweeters: Deriving Sociologically Relevant Demographics from Twitter". In: *Sociological Research Online* 18.3, p. 7.

Snell, J., Swersky, K., and Zemel, R. S. (Dec. 2017). "Prototypical Networks for Few-shot Learning". In: *International Conference on Neural Information Processing Systems (NIPS)*. Long Beach, CA, USA.

Vinyals, O., Blundell, C., Lillicrap, T., Kavukcuoglu, K., and Wierstra, D. (Dec. 2016). "Matching Networks for One Shot Learning". In: *International Conference on Neural Information Processing Systems (NIPS)*. Barcelona, Spain.

Yan, L., Zheng, Y., and Cao, J. (Nov. 2018). "Few-shot learning for short text classification". In: *Multimedia Tools and Applications* 77.22.

Facebook Disaster Maps: Aggregate Insights for Crisis Response & Recovery

Paige Maas
Facebook
pmaas@fb.com

Shankar Iyer
Facebook
shankar94@fb.com

Andreas Gros
Facebook
andreasg@fb.com

Wonhee Park
Facebook
wonheepark@fb.com

Laura McGorman
Facebook
lmcgorman@fb.com

Chaya Nayak
Facebook
cnayak@fb.com

P. Alex Dow
Facebook
adow@fb.com

ABSTRACT

After a natural disaster or other crisis, humanitarian organizations need to know where affected people are located and what resources they need. While this information is difficult to capture quickly through conventional methods, aggregate usage patterns of social media apps like Facebook can help fill these information gaps.

In this paper, we describe the data and methodology that power Facebook Disaster Maps. These maps utilize information about Facebook usage in areas impacted by natural hazards, producing aggregate pictures of how the population is affected by and responding to the hazard. The maps include insights into evacuations, cell network connectivity, access to electricity, and long-term displacement.

In addition to descriptions and examples of each map type, we describe the source data used to generate the maps, and efforts taken to ensure the security and privacy of Facebook users. We also describe limitations of the current methodologies and opportunities for improvement.

Keywords

crisis mapping, crisis informatics, GIS, social media

INTRODUCTION

As social media and messaging apps continue to be important communication tools in people's everyday lives, they have also come to play an important role in how people prepare for, respond to, and recover from disasters (Palen and Anderson 2016; Castillo 2016). They are used by people affected by a crisis event, people responding to it, and people following and observing the event from afar (Olteanu et al. 2015). They can be used for individual and mass communication, information seeking, and gaining situational awareness. A significant body of research in crisis informatics has focused on studying these behaviors, and on developing techniques and tools for harnessing social media and other data sources for improved crisis response.

Many of these tools seek to extract information about what is happening in a crisis from the text of Twitter posts (Reuter et al. 2018), but a sparsity of location metadata can make it difficult to associate the extracted information with explicit locations. Alternatively, crisis maps collect relevant data on a map, frequently through the work of digital volunteers sifting through posts to both social and traditional media (Okolloh 2009), or by accessing geospatial data from official sources. The scale of social media suggests a potential for extracting unprecedented insights into how populations prepare for and react to hazard events, the impact those events have on these populations, and what needs these populations have that are not being met. Unfortunately, a dearth of precise location data can make much of this potential difficult or impossible to realize.

In the course of providing services to their users, many smartphones and smartphone apps regularly collect precise location information. In the case of Facebook, people have an option of whether or not to provide this information to Facebook (Facebook 2019). Location data is used to provide a myriad of services, including helping people find nearby friends, information about nearby Wi-Fi hotspots, and location-relevant ads. This data also enables targeting of AMBER alerts and prompts to check-in as "safe" after a hazard event. In addition to powering Facebook product features, this location data, when aggregated and anonymized, can provide insights about how populations are affected by hazard events as they happen.

While data from phones and apps has enormous potential, it also comes with notable risks for individuals. Location data is sensitive, and misuse could compromise the privacy and safety of individuals and communities. Any attempt to generate insights and share them with humanitarian responders must first address privacy and security to ensure that people are protected.

This paper presents Facebook Disaster Maps, a collection of methods for processing Facebook data into dynamic maps that highlight several key factors of how populations are preparing for, impacted by, and coping with natural hazards. The maps make use of anonymized and aggregated data, including current and historical location data, information about cell site connectivity, and data on phone battery charging. While the raw data for the maps remains available only to Facebook, the aggregated maps, with privacy and security protections like adding random noise and dropping small counts, are shared with humanitarian organizations on an ongoing basis in the days and weeks following a hazard event. The maps are meant to address specific needs that these organizations face in formulating and executing a response, therefore the research and development that goes into the maps has been (and continues to be) informed by discussions between Facebook researchers and individuals at the humanitarian organizations.

We first discuss existing research in the field of crisis informatics that has informed this work. Next, we survey five distinct categories of Facebook Disaster Maps, each of which aims to answer different questions that arise in formulating humanitarian response to hazard events. We discuss the methodology used in building each map and how privacy and security issues are addressed within that methodology. Next, we discuss current limitations on the utility of the maps and ongoing research that aims to overcome some of these limitations. Finally, we give examples of how each of these maps has been utilized by humanitarian organizations in the field.

RELATED WORK

In order to formulate an effective response to a crisis situation, first responders and relief organizations must combine many, diverse sources of information into "situational awareness," or a coherent, big-picture understanding of the situation. In a crisis, this situational awareness includes information about "the status of the hazard agent, damage done to buildings and infrastructure, the location of evacuation centers, and the number and location of injured people and/or animals" (Vieweg 2012), among other things. More generally, Sarter and Woods (1991) describe situational awareness as "all knowledge that is accessible and can be integrated into a coherent picture, when required, to assess and cope with a situation." While situational awareness is essential for some crisis response roles, the focus on a single "big picture" can be insufficient in some cases. It misses the fact that different crisis response roles (from a first responder to a digital volunteer to a humanitarian worker) have different information needs. Zade et al. (2018) argue for a focus on "actionability," which means understanding the different needs of people in different roles and focusing on getting them the information that they can act on.

Much existing crisis informatics research deals with enhancing situational awareness by identifying, extracting insights from, and generating predictions based on social media posts, mostly on Twitter (Vieweg et al. 2010; Cameron et al. 2012; Vieweg 2012; Imran et al. 2013). This is based on the idea of social media users acting as "citizen sensors" (Sheth 2009) who report on conditions as they experience them through their social media posts. Due to the high volume of social media posts during crisis situations, researchers have deployed myriad algorithmic and statistical methods for processing the streams, including natural language processing (NLP), semantic analysis, supervised machine-learned modeling, unsupervised clustering, and others (Castillo 2016).

A prominent approach to organizing and displaying crisis data for increased situational awareness is in the form of a crisis map. Crisis mapping involves the collection, analysis, and geospatial visualization of data. The data involved may come from a variety of sources, including social media and other citizen reports, traditional news reports, and official sources. For example, Google Crisis Maps[1] pulls together and displays public information, including storm paths, flood zones, evacuation routes, and more on top of Google Maps. Crowdsourcing and digital volunteers are used to collaboratively construct crisis maps and other datasets for improved situational awareness. Ushahidi (Okolloh 2009) is a popular and flexible crowd-sourced crisis mapping platform, which allows volunteers to, among other things, pin reports relevant to a crisis onto a shared map. In the immediate aftermath of the January 2010 earthquake in Haiti, volunteers used Ushahidi to collect reports about conditions on the ground from Twitter and other sources on a map (Starbird and Palen 2011; Meier 2012). Another notable achievement was volunteers using satellite photos to improve OpenStreetMap in the affected areas (Soden and Palen 2014). This later gave rise to the Humanitarian OpenStreetMap Team[2], which uses open mapping to support humanitarian action and community development more broadly. Castillo (2016) includes a detailed list of crisis mapping platforms and other tools for analyzing and visualizing insights from social media crisis data.

In their survey of research on social media in crisis management, Reuter et al. (2018) describe several types and aims of existing work related to the work described in this paper. In particular, they discuss the processing of social media data for monitoring ongoing events, and visualizing the results of analysis in order to make these results more salient and useful. These methods and insights frequently culminate in the design and building of tools and systems that address problems that arise in the course of crisis response. Some researchers employ participatory design, where professional crisis responders are involved in the design process of these systems (Hughes 2014; Hughes and Shah 2016). As Reuter et al. (2018) discuss, evaluation procedures for these systems vary widely and are often limited. Hughes and Shah (2016) evaluated the effectiveness of their Twitter-based crisis monitoring application by sitting with and observing public information officers using their tool while responding to wildfires. This allowed them to identify concrete contributions their tool made to the analysis, documentation, and reporting on social media produced by the participants.

Several of the data processing and mapping methods described in this paper highlight how population densities and movement patterns in crisis situations differ from pre-crisis situations. Human mobility has been shown to be highly predictable at city (Yan et al. 2014) and regional/national scale (Simini et al. 2012) in non-crisis times. Some research has found that even though mobility (e.g., travel distances and destinations) does change during crises, it can remain highly predictable (Lu et al. 2012). Wang and Taylor (2016) affirm this over a wide variety of hazard types and impacted regions, though they also found that some of the most severe crises can impact mobility patterns such that they are no longer predictable using pre-crisis states. This suggests that near-real-time insights into human mobility can be useful for gaining situational awareness and administering humanitarian assistance. To that end, Ciravegna et al. (2018), built a system for incorporating location tracking into mobile phone apps, processing the collected location data, and generating near-real-time insights into human movement patterns that may be useful for crisis response and recovery. For example, their visual analytics interface displays the frequency that different routes are taken, which, when compared across crisis and pre-crisis time periods, may highlight dynamic road access constraints. This paper, while using different data sources, builds on this line of work.

DISASTER MAPS DATASETS AND METHODOLOGY

In this section, we describe how each of the five Facebook Disaster Maps are produced. While we start with a brief overview of each type of map, we then describe concepts, privacy protection mechanisms, and computations that are shared by some or all of the map types. Once we have explained each of these, we discuss each type of map individually, including walking through examples based on real events.

Overview of the maps

As mentioned above, there are five distinct map types that make up Facebook Disaster Maps. Here we list each of them and state a fundamental question that each map type is intended to help answer. The first four listed maps rely on a shared calculation procedure where we compare counts of certain events during a crisis to baseline expectations from a pre-crisis period. In most cases, we produce these maps at regular intervals for two weeks after a crisis begins. Over these relatively short time scales, it is plausible that the main causal driver of population-level changes is the crisis event itself. The fifth map type, Displacement maps, relies on a different methodology.

[1] https://support.google.com/crisismaps/
[2] https://www.hotosm.org/

- **Facebook Population:** Where are there more or fewer Facebook users than we would expect based on pre-crisis levels? This can indicate areas that are affected by the crisis, or where evacuations are occurring.
- **Movement:** Which pairs of places are Facebook users moving between more or less often than we would expect based on pre-crisis levels? This can provide signal on large-scale population movements.
- **Power Availability:** Where are Facebook users charging their mobile phones more or less often than we would expect based on pre-crisis levels? In aggregate, this charging behavior can serve as a proxy for the state of the power grid.
- **Network Coverage:** Where does the usage of mobile phones indicate that there are more or fewer cell sites actively serving a location than we would expect based on pre-crisis levels?
- **Displacement:** In the weeks and months following a crisis event, where has the affected population resettled? Unlike the other map types, Displacement maps do not rely on a pre-crisis baseline computation, which can introduce additional complexities and caveats when interpreting the data. This will be discussed in detail in a later section.

Common concepts

There are several concepts relevant to understanding the maps. First of all, we construct maps using two different methods of identifying locations: tiles and administrative polygons. The **Bing Maps Tile System** defines a series of grids at different resolution levels over a rectangular projection of the world (Schwartz 2018). Each level is constructed by dividing the previous level into fourths. We typically use Bing tile levels 13 through 16, where level 13 results in tiles that are about 4.9 x 4.9 km at the Equator. The other method we use for identifying a location is **administrative polygons**, which define the political and geographic boundaries of countries, states, provinces, counties, cities, and more.

When generating a map for a crisis event, we specify a rectangular **bounding box** around the most directly affected area. The different map calculations, described in the following sections, are done relative to this region, and, for most of the maps, only data within this region is included.

Most of the map types are based on counting events that occur within a **time interval**, which is frequently 8 or 24 hours. The time interval determines what data is included in a calculation as well as the minimum frequency with which new maps are generated.

Privacy protection mechanisms

We employ a suite of privacy protection mechanisms in order to obscure the identity and actions of individuals and small groups while preserving the population-level insights that are useful for humanitarian response. Some of these are only applicable to a subset of the map types, which we will indicate in the sections below.

- **Random noise:** A small amount of random noise is added to count data to ensure that it is not possible to ascertain precise, true counts for sparsely populated locations.
- **Spatial smoothing:** We average counts for a location with those of surrounding locations using inverse-distance-weighted averaging. This gives more weight to closer locations and less weight to further locations.
- **Dropping small counts:** Locations with small counts are dropped from the final datasets. In cases where there are both baseline and crisis-time counts (as described in the next section), if either is less than a threshold value then both are dropped.

Common computations for maps with baselines

As mentioned above, four of the map types (Facebook Population, Movement, Power Availability, and Network Coverage) use a shared procedure for computing a pre-crisis baseline that can be compared to observations during and after a crisis. A baseline is computed for each location in a map (which can be a tile, an administrative polygon, or, as we will see for Movement maps, pairs of tiles or polygons). The duration of pre-crisis data available for computing a baseline differs for different source datasets, and is dependent on technical capacity and data retention policies. While these can change over time, all the map types described here use baselines derived from 5-to-13 weeks of pre-crisis data.

When computing a map for a given time interval after a crisis, we account for normally occurring daily and weekly patterns by computing a baseline using only data from the same time-of-day and day-of-the-week in the period preceding the crisis. Therefore, for a given location and time interval, the baseline dataset is composed of a set of counts from the same location over the same time interval on the same day-of-the-week for multiple weeks preceding the crisis.

Once we have collected the baseline dataset, we eliminate extreme values using winsorization. We do this by computing the mean and standard deviation of the pre-winsorization distribution, identifying the 2.5th and 97.5th percentiles of a Gaussian with that mean and standard deviation, and setting values outside those bounds to the lower and upper bound values if they are anomalously low or high, respectively.

With extreme values eliminated from the baseline dataset, we next compute the baseline mean (μ_{baseline}) and standard deviation (σ_{baseline}) from the remaining data. Finally, we compare what is observed in the current crisis time interval (c) to these baseline statistics. The first comparison is the percent difference between crisis and baseline:

$$\frac{c - \mu_{\text{baseline}}}{\mu_{\text{baseline}} + \epsilon} \tag{1}$$

where ϵ is a small value, usually 1. The second comparison is the z-score:

$$\frac{c - \mu_{\text{baseline}}}{\max\left[\sigma_{\text{baseline}}, \sigma_{\text{min}}\right]} \tag{2}$$

were $\sigma_{\text{min}} \approx 0.1$ is introduced to handle the case where there is no variance in the baseline distribution. The z-score highlights the areas on the map with the most significant differences between what is being observed during the crisis and what is typically seen during the baseline, so unless we note otherwise, this is the value presented in the example maps used in this paper. When sharing data with humanitarian organizations, we also include the percent difference, the baseline means, and the crisis counts. All of this data is modified for purposes of privacy preservation using the methods described in the section above, including dropping counts from locations where either the crisis or baseline value is less than a threshold.

Facebook Population maps

These maps show statistics about the aggregate number of people observed in a location (tiles or administrative polygons) in 8-hour intervals following a crisis compared to a pre-crisis baseline period. The counts include people with location services enabled on their mobile device. If the same person appeared at multiple locations in a time interval we only count their most frequent location, choosing the latest of their most frequent locations in the event of a tie. All of the described privacy protection methods are used on these maps to ensure that the locations of individuals or small groups cannot be identified.

Figure 1 shows an example of the Facebook Population maps[3] in the aftermath of Cyclone Gaja, which affected part of South India in November of 2018. The time interval is the 8 hours ending at 13:30 IST on November 17. The red and blue portions of the map show tile-level Facebook Population z-scores, which have been clipped to a range of -3 (dark red) to 3 (dark blue) for clearer interpretability. The eastern coastal region of the map, around the city of Nagapattinam, is where the cyclone made landfall and shows significant drops in the number of observed people compared to the baseline. These drops could be attributed to evacuations, loss of power, loss of network connectivity, or some combination of all three. Many parts of the west coast, on the other hand, demonstrate increases in the population when compared to the baseline.

Movement maps

These maps present statistics about aggregate movement between pairs of locations in subsequent time intervals. As with the Facebook Population maps, we use the baseline computation procedure to measure pre-crisis movement patterns, and compute statistics for comparing this with what is being observed in the post-crisis period.

Figure 2 shows selected movement vectors between administrative regions in the area impacted by Cyclone Gaja. Each line on the map represents a pair of locations for which there has been an observed change in the number of people moving during the baseline and the crisis time intervals. This map displays only the locations of movement

[3]Note that the methods described in this paper are under active development and considered a work in progress. Therefore, the figures reflect the state of our mapping algorithms at the time that they were generated, namely during the two weeks after the crisis event. As such, they do not always reflect the latest state of our algorithms at the time of publication.

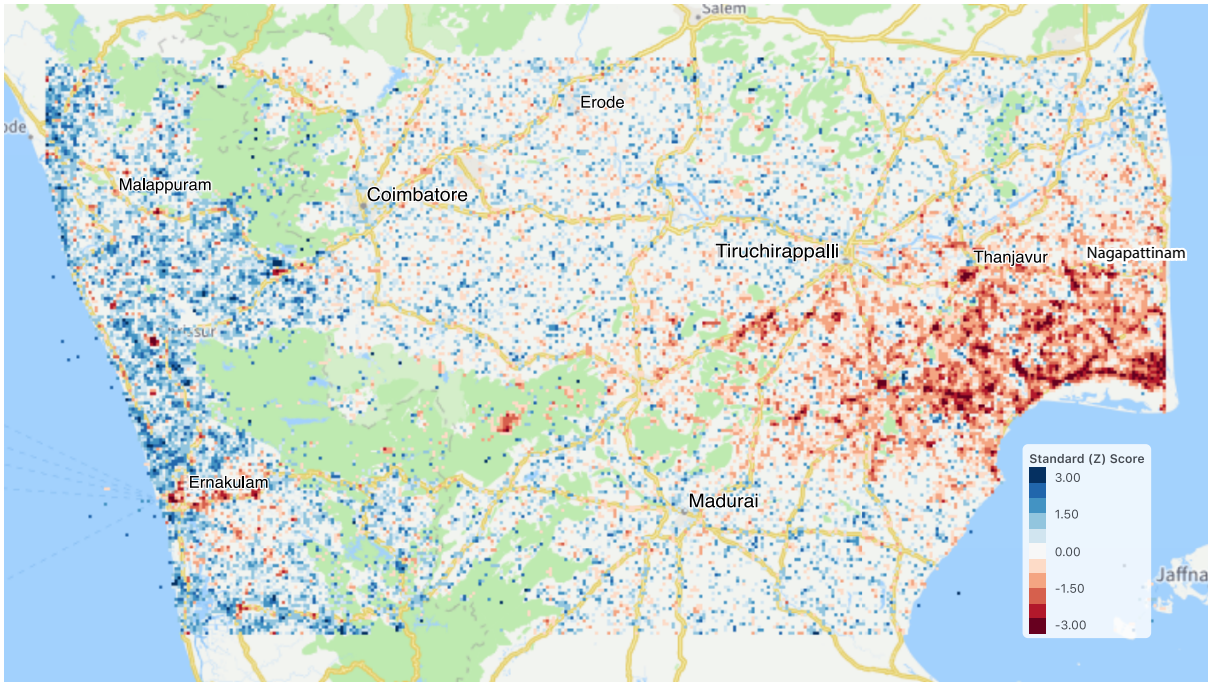


Figure 1. Tile-level Facebook Population map for part of South India on November 17, 2018, in the aftermath of Cyclone Gaja.

vectors. In an interactive visualization, a user of the maps could click on a vector or access the data in tabular form in order to see the actual values. Table 1 shows the percent differences from baseline to crisis for some of the major cities in the map. These differences are based on movement that occurred between eight-hour time intervals ending and beginning at 5:30 IST on November 19, 2018. Because of data sparsity, we only show vectors between larger population centers. While the data in this map does not show a complete picture of what is happening on the ground, it can be useful when combined with other data sources. For example, this map shows a potential increase in travel from Pattukkottai to Thanjavur, and, likewise, from Thanjavur to Tiruchirappalli.

Power Availability maps

For some people with Android devices, it is possible to observe when they connect to a power source. While that power could come from places like cars, generators, or external batteries, when taken in aggregate, it can provide a proxy for the state of the power grid in an area. For each location, these maps count power connection events for devices with location services enabled. We use the baseline computation procedure outlined above to process these counts and produce statistics that highlight where there appear to be significant changes after a crisis when compared to the baseline period. We also use all the privacy protection mechanisms described above in these maps.

Figure 3 shows two more maps related to Cyclone Gaja. The left side of the figure shows the baseline means for connections to power from the 5 weeks preceding the crisis (darker blue indicates more connections), while the right side shows the post-crisis z-scores for the 24-hour period ending November 18, 2018 at 5:30 IST (red indicates negative z-scores). By examining these maps side-by-side, we can see which regions typically show power connections and which of those seem to be experiencing significant drops during the crisis period. These include some of the larger, heavily-impacted cities, such as Nagapattinam, Thanjavur, and Pudukkottai. On the other hand, Tiruchirappalli and Kumbakonam do not appear to have experienced large-scale decreases in connections over this time period.

Network Coverage maps

Cell sites are points of connection in a cellular network made up of antennas with their basestations. A cell tower usually holds multiple such antennas, each of which has a unique identifier. For Android devices with location services enabled, we can use these cell site identifiers to infer network coverage. For each cell site, we draw an estimated coverage area describing the locations of the devices that are accessing that site to obtain cellular connectivity. These inferred coverage areas may overlap, and we count the number that overlap with any tile at any given point in time. These maps are only created for Bing tile locations, not administrative polygons. This

Figure 2. Movement map for Cyclone Gaja on November 19, 2018, highlighting where there were notable differences in movement between pairs of locations when compared to the baseline period.

Starting Location	*Ending Location*	*Percent Difference*
Kumbakonam	Thanjavur	19%
Pattukkottai	Thanjavur	69%
Pudukkottai	Tiruchirappalli	-19%
Thanjavur	Tiruchirappalli	21%
Thanjavur	Kumbakonam	-20%
Tiruchirappalli	Thanjavur	-4%
Tiruchirappalli	Pudukkottai	56%

Table 1. Selected movement data from Cyclone Gaja on November 19, 2018

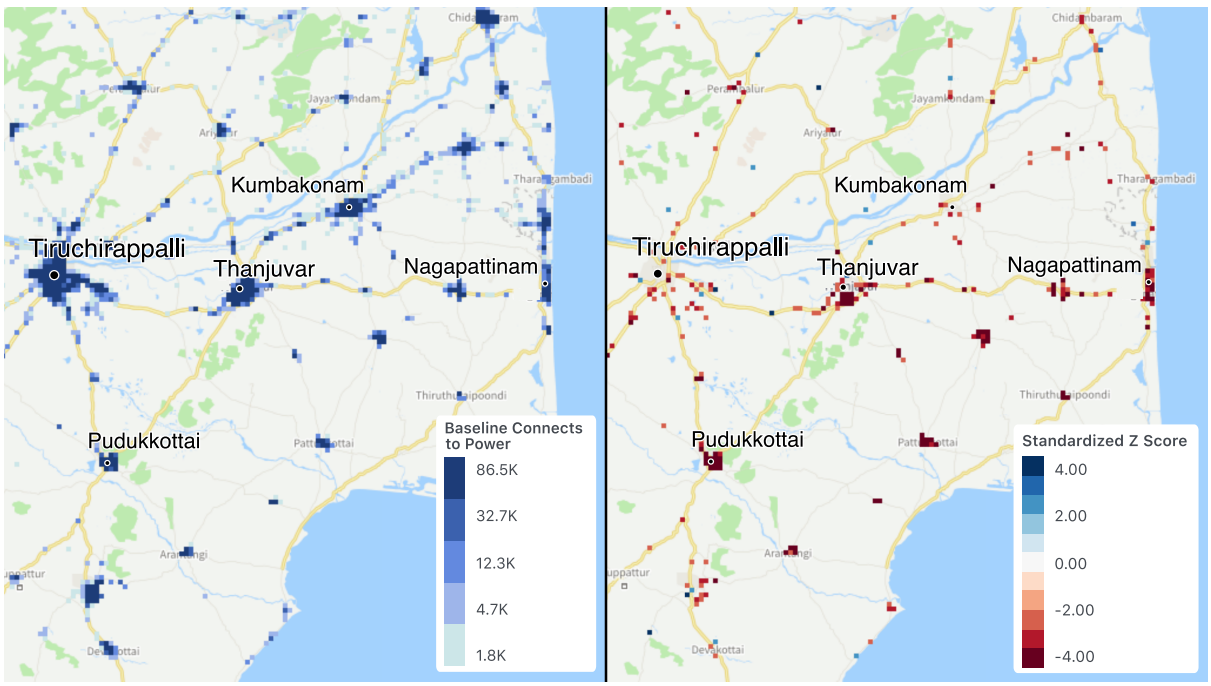


Figure 3. Tile-level Power Availability maps for Cyclone Gaja on November 17, 2018. The map on the left shows the mean power connections from the baseline time period, while the map on the right shows the crisis-time z-scores.

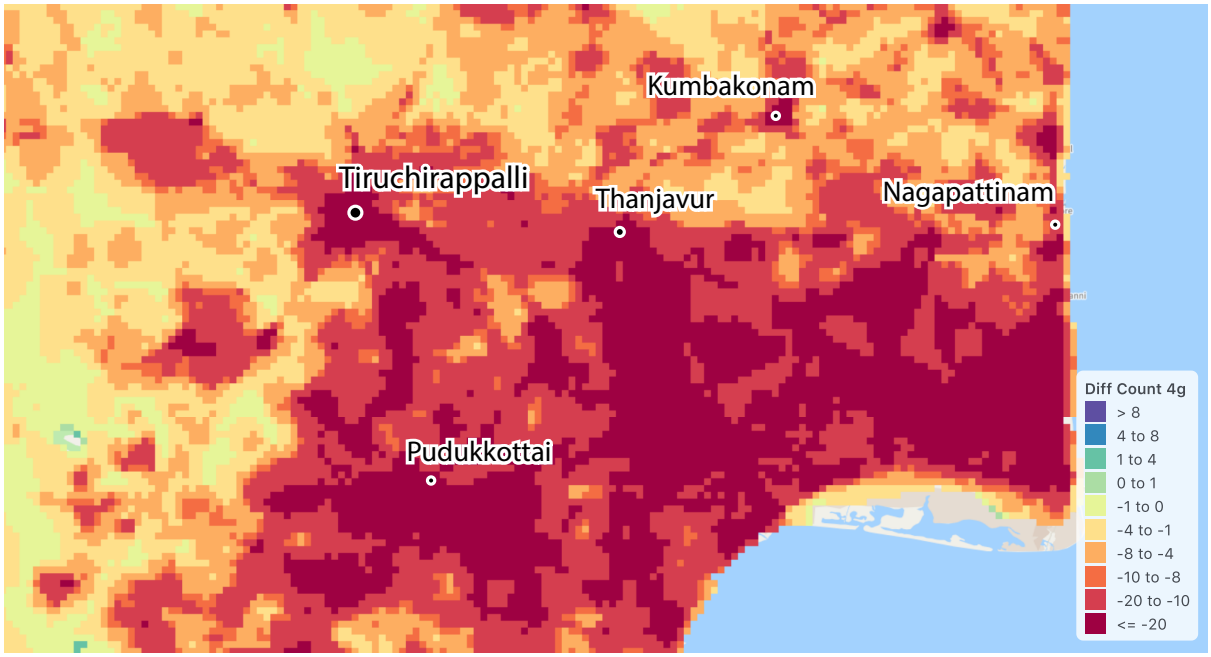


Figure 4. Tile-level Network Coverage map for Cyclone Gaja on November 17, 2018.

count is then compared before and during the crisis using the baseline computation procedure outlined above. We safeguard user privacy by aggregating this data across users and cell sites for each location. Additionally, we drop small counts in the same manner as for the other map types.

Figure 4 shows the a Network Coverage map for a detailed region impacted by Cyclone Gaja based on the 24 hour period ending November 18, 2018 at 5:30 IST. The colors on the map indicate decreases in the number of 4G network connections from a given tile in that time period, compared to the mean connections observed in a three-month baseline period. The patterns observed here echo those in Figure 1, where we saw many fewer people located in the coastal region around the city of Nagapattinam. This highlights an issue where these maps are unable to clearly differentiate between evacuations, loss of power, and loss of connectivity. When considered together, and in combination with other data sources, these maps will provide better, but not complete, clarity about the state of cellular network coverage during a crisis.

Displacement Maps

The final class of Facebook Disaster Maps are long-term displacement maps. The fundamental question that these maps address is the following: in the weeks and months following a hazard event, where has the affected population gone? These maps are based on locations, typically at the city-level, inferred from a person's internet connection.

The calculation procedure for the Displacement maps is as follows:

1. **Home city estimation**

   (a) For everyone who used Facebook from within the bounding box 1-to-5 weeks before the crisis, we identify the most common city from which they accessed Facebook. This city is treated as the person's "provisional" home city.

   (b) For each person identified in step a, we confirm that their most common city in the week immediately preceding the crisis was the same city as in step a. This is meant to filter out people that live in a city but were not present when the crises event occurred. The people that remain make up the effective population for a given home city H.

   (c) We filter to only include the population whose home city, H, is in the bounding box.

2. **Destination city estimation**: For each week following the crisis, calculate the most common city for the population identified in step 1. This destination city, D, does not need to be within the bounding box that defines the affected region.

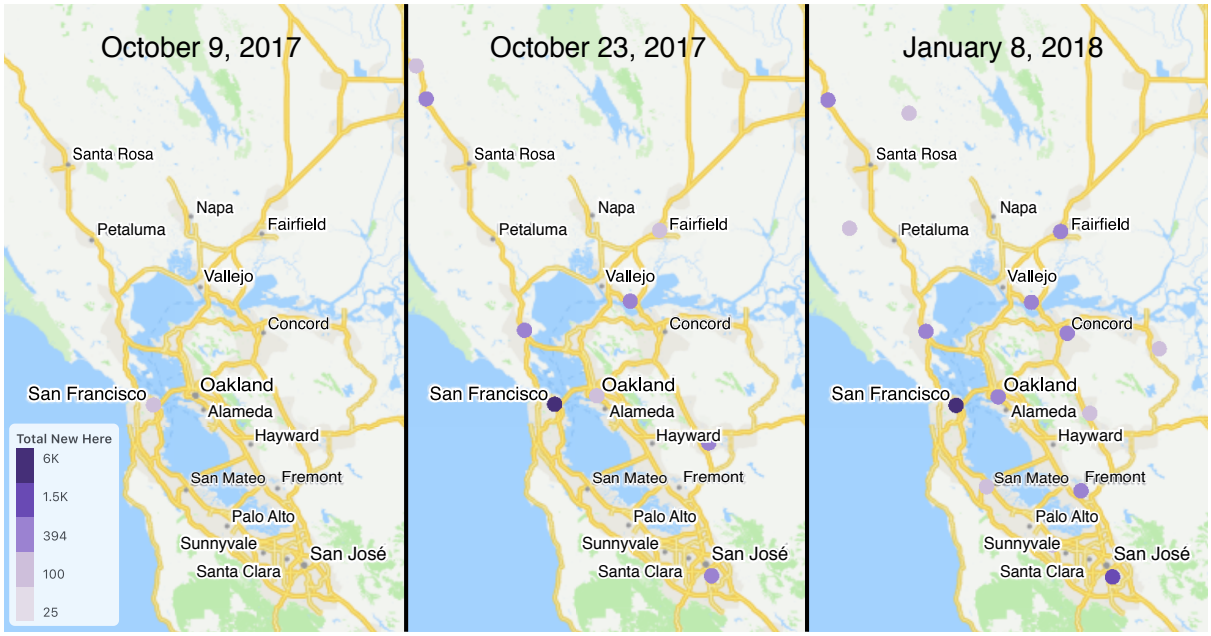


Figure 5. Displacement maps for the Tubbs Fire in the vicinity of Santa Rosa, California at three different points in time. The fire started on October 8, 2017. The maps place purple dots on cities outside of the immediately affected region that have been the destination for at least 100 people who lived within that region.

3. **Home-city-to-destination-city transition estimation**: Aggregate home city-destination city pairs and measure transition counts: of those people from home city H, how many are now in destination city D?

Figure 5 shows examples of the output of these calculations for the Tubbs Fire, which affected Sonoma County, California, in the vicinity of Santa Rosa, in October 2017. The maps place dots on cities outside of the immediately affected region where at least 100 people from the affected region migrated. Darker purple dots indicate the presence of more possibly-displaced people. The fire started on the evening of Sunday, October 8, and we see that on the following day, San Francisco is the only city with a dot. Two weeks later, we see that sufficiently large populations have moved to several cities around the Bay Area. The figure shows only Northern California, but by October 23, more than 100 people had gone to Los Angeles as well. By January 2018, additional Northern California cities appear on the map, and Los Angeles and San Diego would also appear if we zoomed out to include Southern California.

It is not surprising that some people who were in Sonoma County in September 2017 (the time period used to establish the home city estimates) would be in California's major cities by the end of the year. This points to a current limitation of this methodology: Although these maps would ideally measure the population that was forced to migrate because of the crisis, their current state is largely descriptive and does not address that causal question. This may not be a problem in the immediate aftermath of a crisis if we assume that the hazard event is the main driver of mobility in that period. However, as time progresses, the counts of transitions between cities become confounded by several other factors, such as seasonal effects, normal population flows, and fluctuations in rates of Facebook usage by the fixed population under consideration. Unlike our other maps, the displacement maps do not currently include any comparison of the observed counts to "baseline" values that encapsulate what we ought to have expected in the absence of a crisis event. Performing such a comparison could help isolate the causal effect of the crisis itself, and we describe ongoing work in this direction in the next section.

LIMITATIONS AND FUTURE WORK

The maps described above have the potential to provide a picture of crisis situations with a novel level of detail, timeliness, and global coverage. That being said, this picture is imperfect and has a number of notable limitations. In this section we discuss these limitations and directions for future research to address them.

First, our data sources are not representative of the population affected by crises, especially in regions where Facebook penetration is low. Moreover, for most of our maps, there is the additional restriction that we rely on Facebook users who have location services enabled. Drawing inferences based on their behavior may lead to a skewed picture of what is happening on the ground. We attempt to mitigate the risk this poses by ensuring that

partner organizations that utilize the maps understand these limitations and use them in combination with other sources of data in a process of triangulation.

In a similar vein, because our data sources depend on signals received by Facebook, different maps may conflate trends in people's movement, connectivity, and power availability. To give a concrete example, if the Facebook Population map shows a decrease in the number of people in a crisis region and the Network Coverage map shows a reduced number of active cell sites, we cannot be sure whether some people have evacuated, internet access has been disrupted, or both.

Recognizing these limitations, we are engaged in ongoing efforts to make the maps more useful and representative of the on-the-ground situations during crises. We are studying how Facebook users with location services enabled differ from the general population in different parts of the world. We seek to characterize this bias, understand how it affects insights drawn from the maps, and, ultimately, correct for it.

Apart from the representativeness issue, our maps may not always isolate the consequences of the hazard event from all other potentially confounding effects. This is particularly problematic for the Displacement maps, because they attempt to measure long-term effects. Many things can happen in the intervening time between the hazard event and map generation: there can be confounding effects from holidays, school schedules, other crises, etc. We are currently working on developing a baseline methodology for this map as well that could help isolate the causal effect of the hazard event.

REPORTS OF USAGE FROM THE FIELD

Since the launch of Disaster Maps in June of 2017 (Jackman 2017), our partners have grown to include more than 30 of the world's most significant nonprofits and UN agencies in disaster response, including the International Federation of the Red Cross, the World Food Programme, the United Nations Children's Fund (UNICEF), NetHope, Direct Relief, and others. Facebook has recruited partners for this effort through multiple channels, including a training partnership with the NetHope consortium, comprised of nearly 60 international NGOs with an interest in the use of technology for humanitarian response.

In the nearly two years since Disaster Maps launched, the maps have been used during major disasters in nearly every region of the world. When Hurricane Maria struck the island of Puerto Rico, NetHope and the American Red Cross used the maps to inform their deployment of nearly 100 Wi-Fi hotspots across the island to the areas that needed them most (Brinkhurst and Crowley 2018). During Hurricanes Florence and Michael, Humanity Road used the Facebook Population maps to monitor large-scale evacuations and determine where communities were still sheltering in place, sharing these insights with FEMA, the US Coast Guard, and state-response agencies (Waggoner 2018). During the Thomas, Carr, Mendocino Complex, and Camp Fires, Direct Relief used the maps to monitor how populations affected by wildfires were moving and then used this to guide distribution of hundreds of thousands of respiratory masks, as well as to coordinate with networks of health centers to alert hospitals that might see increased volumes (Snibbe 2018).

In August of 2018, Kerala, India experienced severe flooding that displaced over a million people. SEEDS India used the Facebook Population and Displacement maps to appropriately time their early recovery phase. After identifying when people appeared to begin to return home, SEEDS launched a nationwide collection drive for widely needed items (Gupta 2018).

When volcanic eruptions in Guatemala and a combined earthquake and tsunami struck the island of Sulawesi in Indonesia, UNICEF used the Network Coverage maps to determine how many people could be reached through U-Report, an outreach tool built on Facebook Messenger. In Guatemala, UNICEF reached 3,000 new people with information about what to do after the eruption and in Indonesia, U-report reached 3,500 people within 48 hours to understand how they were impacted (Brecha Cero 2018). As part of this deployment, UNICEF was better able to deliver on needs related to water, child protection, health and nutrition in collaboration with the Government of Indonesia and United Nations Office for the Coordination of Humanitarian Affairs.

CONCLUSION

We have described the data and methodology behind Facebook Disaster Maps, a collection of geospatial datasets meant to contribute to situational awareness during disasters. The maps are based on aggregated and anonymized data that is collected and employed in the course of Facebook usage, including current and historical location data, information about cell site connectivity, and data on phone battery charging. The privacy and safety of Facebook users is a primary concern, and a number of methods are employed to maintain privacy, including filtering and obscuring cases where data is sparse.

We describe five types of maps. The Facebook Population maps show regions where more or fewer Facebook users are present when compared to pre-crisis periods. This can highlight areas where people are evacuating from or to. The Movement maps show how movement between pairs of locations differs during and before a crisis. The Power Availability maps show where the crisis has been accompanied by a reduction in the number of people charging their phones, which can indicate disruptions in the power grid. The connectivity maps show regions with reduced connections from phones to particular cell sites, which can indicate connectivity loss for those sites. Finally, the Displacement maps show, in the weeks and months following a crisis, indications of the magnitude of the population that has been displaced from their home city and what cities that population has been displaced to.

In the section "Limitations and Future Work," we discussed a number of limitations of the maps that prevent them from being more useful to humanitarian responders. Our ongoing work aims to surmount several of these limitations, for example the problem of isolating the causal effects of the crisis on long-term displacement and the issue of representativeness across all five map types. One overarching goal of all of our research efforts is to better isolate the most actionable information in each map from the less relevant details. That goal will, however, never be perfectly attainable, given the uniqueness of each crisis event. Therefore, our partner organizations will always need to supplement our maps with other sources of data and with their own domain expertise to effectively formulate humanitarian responses.

A rigorous evaluation of the utility of Disaster Maps for humanitarian response is difficult, but should be attempted in future work. In lieu of such an evaluation, in the section "Reports of Usage from the Field," we have collected anecdotal reports of how the maps have been used in practice. While this does not substitute for more formal evaluation, it does provide evidence that the novelty of the data source, the spatial resolution, and the up-to-date nature of these datasets have provided concrete value for the organizations that have used them.

ACKNOWLEDGMENTS

We are indebted to the many people at Facebook who have developed and maintained the systems and infrastructure upon which Disaster Maps are built. We would also like to thank several specific colleagues on the Disaster Maps project, who have contributed to its creation and development and who have also provided helpful feedback on this paper. These collaborators include Molly Jackman, Chang Lang, Eugenia Giraudy, Sourav Chatterjee, Peter Tu, Lior Berry, Alex Pompe, and Sarah Vieweg. Finally, we'd like to thank each of the humanitarian organizations that have worked with us to make Disaster Maps a success.

REFERENCES

Brecha Cero (2018). *Por qué la información en las redes sociales marca una diferencia en los desastres naturales*. Brecha Cero. URL: http://brechacero.com/por-que-la-informacion-en-las-redes-sociales-marca-una-diferencia-en-los-desastres-naturales/.

Brinkhurst, M. and Crowley, J. (2018). *Unlocking Insights from Data: Collaboration with Private Sector creates Cutting-Edge Maps for Disaster Response*. NetHope Blog. URL: https://nethope.org/2018/09/10/unlocking-insights-from-data-collaboration-with-private-sector-creates-cutting-edge-maps-for-disaster-response/.

Cameron, M. A., Power, R., Robinson, B., and Yin, J. (2012). "Emergency Situation Awareness from Twitter for Crisis Management". In: *Proceedings of the 21st International Conference on World Wide Web*. WWW '12. ACM.

Castillo, C. (2016). *Big Crisis Data: Social Media in Disasters and Time-Critical Situations*. 1st. New York, NY, USA: Cambridge University Press.

Ciravegna, F., Gao, J., Ingram, C., Ireson, N., Lanfranchi, V., and Simanjuntak, H. (2018). "Mapping Mobility to Support Crisis Management". In: *15th International Conference on Information Systems for Crisis Response and Management*. ISCRAM '18.

Facebook (2019). *Facebook Privacy Basics: Location*. URL: https://www.facebook.com/about/basics/manage-your-privacy/location (visited on 03/21/2019).

Gupta, M. (2018). *Shedding light on displacement trends in disasters through technology?* LinkedIn. URL: https://www.linkedin.com/pulse/shedding-light-displacement-trends-disasters-through-technology-manu/.

Hughes, A. L. (2014). "Participatory Design for the Social Media Needs of Emergency Public Information Officers". In: *11th International Conference on Information Systems for Crisis Response and Management*. ISCRAM '14.

Hughes, A. L. and Shah, R. (2016). "Designing an Application for Social Media Needs in Emergency Public Information Work". In: *Proceedings of the 19th International Conference on Supporting Group Work*. GROUP '16. ACM.

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., and Meier, P. (2013). "Extracting Information Nuggets from Disaster- Related Messages in Social Media". In: *10th International Conference on Information Systems for Crisis Response and Management*. ISCRAM '13.

Jackman, M. (2017). *Using Data to Help Communities Recover and Rebuild*. Facebook Newsroom. URL: https://newsroom.fb.com/news/2017/06/using-data-to-help-communities-recover-and-rebuild/.

Lu, X., Bengtsson, L., and Holme, P. (2012). "Predictability of population displacement after the 2010 Haiti earthquake". In: *Proceedings of the National Academy of Science* 109.29, pp. 11576–11581.

Meier, P. (2012). *How Crisis Mapping Saved Lives in Haiti*. National Geographic Newsroom. URL: https://blog.nationalgeographic.org/2012/07/02/how-crisis-mapping-saved-lives-in-haiti/.

Okolloh, O. (2009). "Ushahidi, or 'testimony': Web 2.0 tools for crowdsourcing crisis information". In: *Participatory Learning and Action* 59, pp. 65–70.

Olteanu, A., Vieweg, S., and Castillo, C. (2015). "What to Expect When the Unexpected Happens: Social Media Communications Across Crises". In: *Proceedings of the 18th ACM Conference on Computer-Supported Cooperative Work and Social Computing*. CSCW '15. ACM.

Palen, L. and Anderson, K. M. (2016). "Crisis informatics—New data for extraordinary times". In: *Science* 353.6296, pp. 224–225. eprint: http://science.sciencemag.org/content/353/6296/224.full.pdf.

Reuter, C., Hughes, A. L., and Kaufhold, M.-A. (2018). "Social Media in Crisis Management: An Evaluation and Analysis of Crisis Informatics Research". In: *International Journal of Human–Computer Interaction* 34.4, pp. 1–15.

Sarter, N. B. and Woods, D. D. (1991). "Situation Awareness: A Critical But Ill-Defined Phenomenon". In: *The International Journal of Aviation Psychology* 1.1, pp. 45–57.

Schwartz, J. (2018). *Bing Maps Tile System*. URL: https://docs.microsoft.com/en-us/bingmaps/articles/bing-maps-tile-system (visited on 01/07/2019).

Sheth, A. (2009). "Citizen Sensing, Social Signals, and Enriching Human Experience". In: *IEEE Internet Computing* 13.4, pp. 87–92.

Simini, F., González, M. C., Maritan, A., and Barabási, A.-L. (2012). "A universal model for mobility and migration patterns". In: *Nature* 484, pp. 96–100.

Snibbe, K. (2018). *How technology is helping responders save lives during disasters like the California wildfires*. The Orange County Register. URL: https://www.ocregister.com/2018/08/21/how-technology-is-helping-those-responding-to-disasters-like-the-california-wildfires-save-lives/.

Soden, R. and Palen, L. (2014). "From Crowdsourced Mapping to Community Mapping: The Post-earthquake Work of OpenStreetMap Haiti". In: *Proceedings of the 11th International Conference on the Design of Cooperative Systems*. COOP '14. Springer International Publishing.

Starbird, K. and Palen, L. (2011). ""Voluntweeters": Self-organizing by Digital Volunteers in Times of Crisis". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '11. ACM.

Vieweg, S. (2012). "Situational Awareness in Mass Emergency: A Behavioral and Linguistic Analysis of Microblogged Communications". PhD thesis. University of Colorado at Boulder.

Vieweg, S., Hughes, A. L., Starbird, K., and Palen, L. (2010). "Microblogging During Two Natural Hazards Events: What Twitter May Contribute to Situational Awareness". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '10. ACM.

Waggoner, M. (2018). *Facebook Tool Helps Charities Find Evacuees Who Need Help*. U.S. News & World Report. URL: https://www.usnews.com/news/healthiest-communities/articles/2018-09-18/facebook-tool-helps-charities-find-evacuees-who-need-help.

Wang, Q. and Taylor, J. E. (2016). "Patterns and Limitations of Urban Human Mobility Resilience under the Influence of Multiple Types of Natural Disaster". In: *PLOS ONE* 11.1, pp. 1–14.

Yan, X.-Y., Zhao, C., Fan, Y., Di, Z., and Wang, W.-X. (2014). "Universal Predictability of Mobility Patterns in Cities". In: *Journal of the Royal Society Interface* 11.

Zade, H., Shah, K., Rangarajan, V., Kshirsagar, P., Imran, M., and Starbird, K. (2018). "From Situational Awareness to Actionability: Towards Improving the Utility of Social Media Data for Crisis Response". In: *Proceedings of the 21st ACM Conference on Computer-Supported Cooperative Work and Social Computing*. CSCW '18. ACM.

#CampFireMissing: An Analysis of Tweets About Missing and Found People from California Wildfires

Humaira Waqas*
Qatar Computing Research Institute
Hamad Bin Khalifa University
Doha, Qatar
humaira.waqas@comsats.edu.pk

Muhammad Imran
Qatar Computing Research Institute
Hamad Bin Khalifa University
Doha, Qatar
mimran@hbku.edu.qa

ABSTRACT

Several research studies have shown the importance of social media data for humanitarian aid. Among others, the issue of missing and lost people during disasters and emergencies is crucial for disaster managers. This work analyzes Twitter data from a recent wildfire event to determine its usefulness for the mitigation of the missing and found people issue. Data analysis performed using various filtering techniques, and trend analysis revealed that Twitter contains important information potentially useful for emergency managers and volunteers to tackle this issue. Many tweets were found containing full names, partial names, location information, and other vital clues which could be useful for finding missing people.

Keywords

social media, Twitter, missing and found people, California wildfires, disaster response

INTRODUCTION

Natural and human-induced disasters bring challenges and uncertainties among victims and emergency managers. A recent destructive wildfire in California (a.k.a Campfire)[1] started on November 8, 2018, in Butte County, in Northern California later covered the densely populated foothill town of Paradise caused total damage worth $16.5 billion, destroyed more than 18,000 structures, and at least killed 86 people. In the early days of the fire, among several challenges that formal response organizations faced, the rapid increase in the number of people unaccounted for was a significant concern. The list of missing people once skyrocketed to more than 1,200. This work focuses on the issue of missing people during the California wildfire disaster and analyzes data related to this issue on social media.

People are increasingly using social media platforms such as Twitter during disasters and emergencies. Several research studies have revealed that information available on social media platforms could be useful for a variety of humanitarian purposes (Starbird et al. 2010; Heverin and Zach 2010). For instance, reports of urgent needs of affected people, information about injured or deceased people, reports of damages to the built structure can help formal response organizations enhance situational awareness (Imran, Castillo, Diaz, et al. 2015; Castillo 2016; Alam, Ofli, et al. 2018). Moreover, when official helpline numbers are down or overwhelmed, the general public turns to social media to get the latest updates about an ongoing disaster event to prepare their plans accordingly.

This work seeks to investigate the role of social media platforms, in particular Twitter, during the California wildfire event. Specifically, we focus on analyzing the content of tweets related to missing and found people. To the best of our knowledge, no previous study has analyzed Twitter data in-depth from the perspective of the missing and found people issue, especially during disaster situations, thus it is not known whether and in what form people share information related to this issue on Twitter. For this reason, we first aim to answer the following question. Does

*Work done while the author was an intern at QCRI.
[1] https://en.wikipedia.org/wiki/Campfire_(2018)

Twitter contain information about missing or found people? If the answer to this question is affirmative, we seek to understand what types of information are available on Twitter related to this issue? For example, do people share the names of their family members and friends who are missing? Do they also share location or other relevant information which can be useful in this context? Moreover, we determine whether such information, if present, can be helpful for emergency managers, volunteers, or the family members of missing people?

To answer the above questions, we first select tweets relevant to the missing people issue by applying various filtering techniques on the data collected during the California wildfire event. Next, by identifying trends and spikes which occurred due to high activities on Twitter during the timeline of the whole event, we select tweets from peaks and perform their content analysis. Our analysis reveals that the communications on Twitter during the California wildfire event indeed contain very useful information about missing and found people. We observe tweets with the names of missing and found people. Moreover, several tweets found to have a location and other helpful information such as how the missing person looks like, where he/she was seen last time etc. Such information can be very useful for emergency managers, officials and volunteers who are tasked to find missing people, if identified and processed timely using automatic techniques and systems such as (Nguyen, Joty, et al. 2016; Imran, Castillo, Lucas, et al. 2014).

LITERATURE REVIEW

Over the last few years, social media platforms have been used for several disaster response and management tasks such as situational awareness (Vieweg et al. 2010; Starbird et al. 2010). Research studies have revealed that social media contains a variety of information useful for disaster managers and first responders. This information includes reports of injured or dead people, infrastructure damage, urgent needs of affected people and so on (Imran, Castillo, Diaz, et al. 2015; Castillo 2016). Lindsay 2011 reports the results of a study commissioned by American Red Cross, that social media platforms are the fourth most popular sites which are used by people during a crisis, particularly for information gathering, information sharing, and for help and support purposes.

Although, several empirical analyses from different perspectives have been performed on social media data (Rosser et al. 2017; Wang et al. 2016; Acar and Muraki 2011), to the best of our knowledge no previous work has focused on studying the issue of missing and found people during natural or human-induced disasters. A recent study, which is not disaster-related, conducted by Tsoi et al. 2018, explored the effectiveness of Twitter to find missing persons suffering from dementia (a syndrome leading to progressive cognitive functional loss). The study showed convincing results, concluding that Twitter can also be helpful like traditional news reports in searching a person who got lost due to dementia (Kirkman 2006; Rowe et al. 2011). In an other study conducted by Hunt et al. 2010, the authors discusses the outcomes which can be witnessed if a driver suffering from dementia gets lost. The authors in this study accessed reports of lost drivers given by newspapers and media and concluded that patients who are lost while driving can face tragic incidents leading to death.

In this paper, we use Twitter to explore a potential issue of missing people during disasters and emergencies. We aim to analyze Twitter data shared during a wildfire event to determine whether the general public report about their missing family and friends or not. Moreover, we seek to understand what are the most prominent types of information available on Twitter related to the issue of missing and found people. We believe this study serves as a piece of foundational evidence to the research community to explore further and develop computational systems for the mitigation of this issue.

METHODOLOGY

To investigate whether Twitter data can be helpful for the missing and found people issue, we devise a methodology consisting of four steps. First, we collect Twitter data using a set of keywords during the California wildfires event. Next, we apply different filtering approaches to select the most relevant data to the issue of missing people. Third, we perform a trend analysis by plotting the frequency of tweets throughout the event and identify spikes. Lastly, we perform the content analysis of tweets taken from spikes and peaks. We describe these steps in detail in the following subsections.

Data filtering

Three types of filters are used to select relevant tweets. Specifically, in the first filter, we consider tweets mentioning the names of missing or found people; second, tweets containing particular hashtags related to the missing people issue; and the third filter selects tweets having keywords/terms related to this issue. To find tweets containing names, we first curate a list with names of missing and found people by manually searching different lists on the Internet at

the time of data analysis (i.e., January 2019). To find tweets containing hashtags relevant to the missing or found people issue, we first extract all the hashtags from our data and then manually search through them to find the relevant hashtags. To find tweets using keywords/terms relevant to the missing and found people, we first manually curate a list of terms and then search tweets containing one of those terms.

These three data filtering steps, which we describe in detail in the next section, are applied to the whole tweets set to extract tweets relevant to the issue of missing or found people. All of our further analysis uses the selected tweets.

Data analyses using emerging trends

Social media communications, in particular, Twitter, have reached unprecedented levels. Millions of users post tweets to report their thoughts, events around them, and breaking news. Each tweet is associated with a timestamp (i.e., the date and time when the tweet is posted), a user (i.e., the author of the tweet), and a short text, among many other meta-information. When a large number of Twitter users start posting about a similar topic (e.g., using a hashtag) at a given time/day, it becomes an emerging topic, which is also known as a trend on Twitter. Research studies have revealed that emerging topics often represent significant developments about an ongoing event and a real-time analysis of them can help understand the situation.

To identify significant moments during the California wildfire event, we plot day-wise distributions of both the original tweets and retweets retrieved after the data filtering steps (as described above). The emerged trends give us times and a subset of data where any significant activity happened during the wildfire event. We then closely analyze those trend and spikes to lay down our findings.

DATASET AND DESCRIPTION

Data collection

Twitter data: To collect data from Twitter during the California wildfire, we used the AIDR platform (Imran, Castillo, Lucas, et al. 2014), which is a free and open platform to collect and classify social media data for humanitarian purposes. In total, we collected approximately 4.8 million tweets from November 10, 2018, to December 7, 2018, using keywords *"California wildfire, California wildfires, California fire, California fires, Camp fire, California victims, California rescue"*.

Finding names of missing and found people (ground truth): One of the most important clues to determine whether a tweet is about any missing or found person, is to detect if the tweet contains the name of a person who is declared missing or found in an official list. With this hope that people mention the names of their loved ones who are missing in their tweets, we searched for records of missing or found people names on the Internet. The search result revealed a couple of lists shared by different sources including official, media, and volunteers. These lists contain names of missing and found people and were posted on various dates during the wildfire event. Many names were found redundant; thus we compiled a consolidated list having unique names. We include full names (i.e., when first and last names are available) and partial names (i.e., when either first or last name is present) in the final list of unique names. The consolidated list contains 4,167 unique full names and 3,363 unique partial names and referred as the Internet list in the rest of the paper.

The datasets used in this paper are available at: https://CrisisNLP.qcri.org/

Data filtering and selection

Since the focus of this work is to analyze tweets related to missing and found people, we apply various filters to select the data associated with this issue. Next, we provide details of these filters.

Name-based filtering

This filter aims to select tweets which contain one or more full or partial names of missing or found people. For this purpose, we use the Internet names list to find tweets which match any of the names. Due to some partial names like "Shell", "Donald", "Have" etc., a large number of tweets are retrieved. We further reduced this set by discarding exact duplicates. This filter yields 306,198 tweets in total from which 409 tweets were found to have at least one full name and 305,789 with at least one partial name.

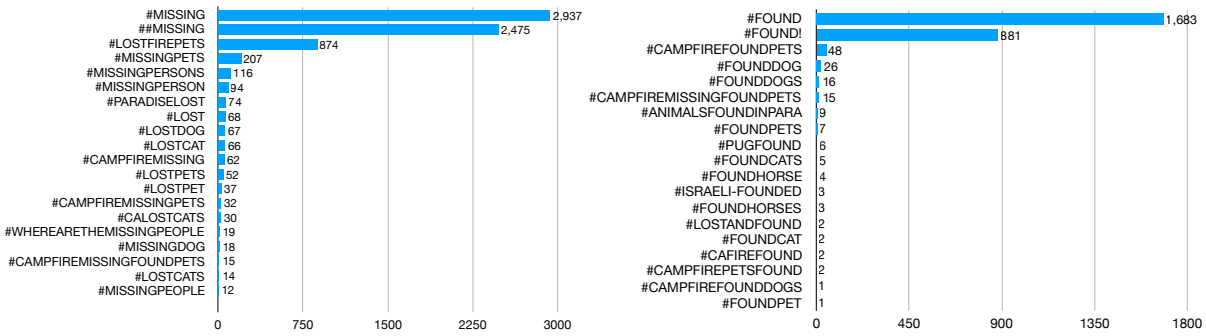


Figure 1. Top hashtags related to the missing (left) & found (right) people/pets issue

Hashtag-based filtering

Hashtags on Twitter allow users to tag a tweet with one or more topics. Famous hashtags start appearing on Twitter trends, which then allow users to search through related content easily. For example, #CampFire was one of the most used hashtags during the Campfire (California wildfires) event. To determine hashtags related to the missing and found people issue, we first extract all the hashtags used in the collected data. Hashtags related to the missing and found people issue are then manually selected from the list of extracted hashtags. In total, 63 hashtags were selected pertaining to missing-related and 19 to found-related tweets. Figure 1 shows the top 20 hashtags and their frequencies for both missing and found people and pets. Next, we find tweets containing at least one of the selected missing or found hashtags. This filter yields a total of 7,404 tweets having at least one of the missing hashtags and 2,720 tweets with at least one of the found hashtags. The complete list of hashtags are provided with the shared data.

Keywords-based filtering

After selecting tweets which fulfill the above two selection criteria, we may still miss tweets which are relevant but not mentioning any names or one of the selected hashtags. To overcome this potential issue, the third data selection strategy tries to find tweets based on keywords/terms related to the missing or found people issue. We use the following terms for this purpose. Missing-related terms: *"missing, search, searching, finding, find, looking, heard, contact"* and Found-related terms: *"found, safe, update, located"*. Next, tweets having one of these terms are selected, which were 144,113 for the missing case and 61,072 for the found case.

After removing the exact duplicates, the resultant set from all of the above filters consists of 340,452 tweets. We use these tweets for our further analysis.

TREND ANALYSIS

Trends related to the names of missing and found people

Figure 2 shows the day-wise distribution of the tweets and retweets containing at least one full name (left-side plot) and one partial name (right-side plot). Generally, on Twitter the proportion of retweets to tweets is always higher, we observe the same pattern in the case of missing and found people tweets in the both full names and partial names cases. Trends and spikes help find significant developments. In this case, the two obvious spikes of the retweets containing the full names are on November 11 and on November 25. We closely investigate these two dates and found the following important reports.

On November 11, a total of 72 tweets and 644 retweets were posted which were having at least one full name from our list. The following tweet about a missing person named "Barbara Carlson" was posted on November 11 at 00:08:15 2018[2], which received 322 retweets on the same day.

"HELP: my grandma (Barbara Carlson) and her dog (strawberry) are missing in the Camp Fire in paradise! My dad and I have been searching refugee camps with no luck. Her address is 5577 heavenly place, paradise California. We believe SHE IS STILL IN THE HOUSE."

The tweet clearly mentions the name of the missing person, and in this case the name of the missing pet too. Moreover, the tweet author specifies the address of the missing person. Several hours later on the same day at 05:01:05 2018, the following tweet about the same person was posted by another Twitter user.

[2]The time zone of all the times mentioned in this paper is UTC.

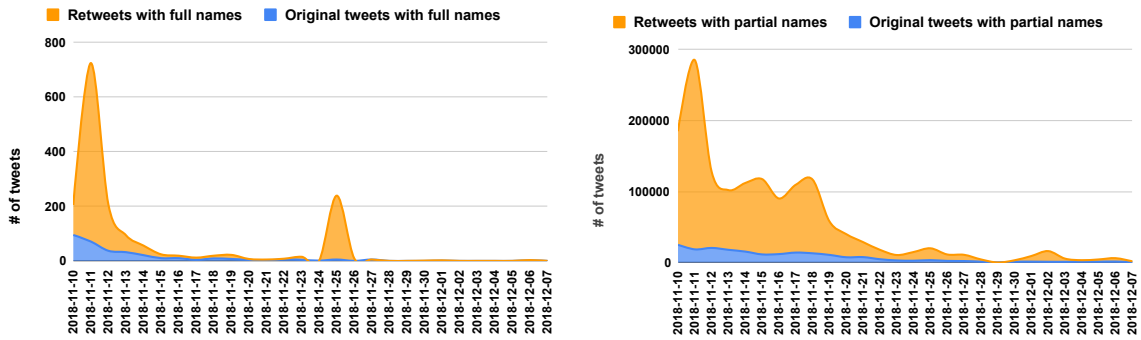


Figure 2. Distribution of tweets with at least one full name (left) and at least one partial name (right)

"The family of Barbara Carlson, who lived on Heavenly Place in Paradise with her sister Shirley and dog Strawberry, are still looking for her. She's 4'11 with gray peppery hair, freckles on her face and glasses. CampFire".

This tweet contains more information about the missing person i.e., the missing person lives with her sister and is 4'11 with gray peppery hair, freckles on her face and glasses. These are all important pieces of information useful for emergency officials and volunteers who are tasked to find missing people.

An update in the form of the following tweet came on November 12 confirming the sad demise of Barbara Carlson and her sister.

"Thank you for all the amazing support from everyone. We got confirmation the house where my grandma and her sister lived had two bodies found today. Barbara Carlson and Shirley Haley were two loved victims of the camp fire."

On the same day, we found several tweets (see below a few cases) reporting missing people and asking help.

T1: "Camp Fire Paradise, CA Missing Marc Handschuh who knows him, and has seen in the last few days, or has contact with him and Christina - Please let us know, we miss him"

T2: "@975krock @hitsfm @VOCMOpenline former coworkers please pray for my Uncle Randy Dodge who is still missing in the Paradise California fires! If you have any connections in the area please let me know. His house has burned down and we have called everywhere!"

T3: "We are looking for Tracey Philipson. If you have any information please contact"

T4: "A son looking for his mother, Barbara Allen who is well-known in Paradise, asked for help at the Camp Fire community meeting held at Chico State Saturday evening."

Moreover, we observe tweets about found people on the same day. For example, "Martin Sheen", who went missing in the early days, is reported found on November 11 in this tweet:

"Martin Sheen has been found after his son Charlie Sheen feared he had gone missing in the devastating wildfires in Southern California."

Another tweet about a found person came like this: "FOUND- Dan Sloane Camp Fire has been located and is safe with his two dogs."

A relatively small spike on November 25 also reveals important updates. One tweet that received more than 100 retweets out of all 208 tweets posted on that day was the following reporting several still missing.

"Soon Warner would discover that no one knew where his uncle Greg Rader, his aunt Michelle Sherman, his grandma Anne Thomas Sherman or his grandpa Fay Hubert Sherman were. His 96 yr old Grandpa was a WW2 Vet and was still living with his wife in Paradise."

Similarly, the following tweet posted on November 25 reports about a person (Sheila Santos) who was still missing several weeks after.

"STILL MISSING: Sheila Santos of Paradise. campfire campfiremissing campfirejameswoods"

We try to look back into our data and found that the first report about "Sheila Santos" came on November 13 in the form of the following tweet.

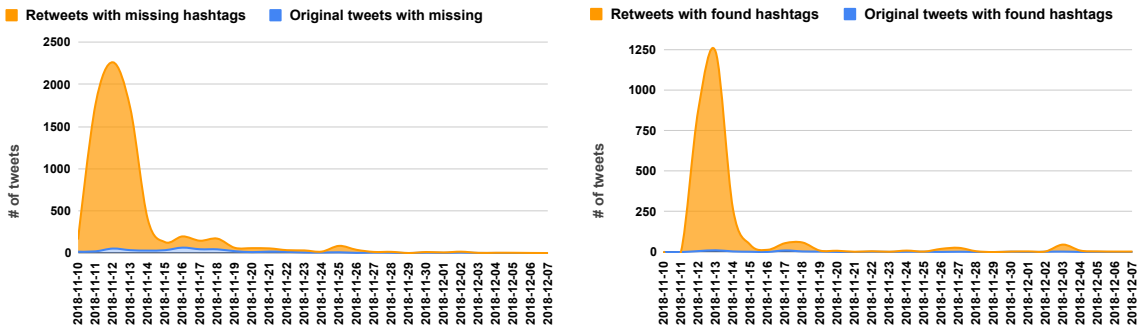


Figure 3. Distribution of original and retweets with missing hashtags (left) and with found hashtags (right)

"The last time anyone spoke to Sheila Santos, she was still groggy from sleeping pills. By that point the CampFire had already swept through town, and the roads leading to her Paradise trailer were closed."

The final update (see the following tweet) about "Sheila Santos" came on December 1 when sadly she found dead.

"Sad to report that, Tammie Konicki just learned that her mother's remains were found. Sheila Santos, 64, was another person killed in the state's deadliest and most destructive wildfire. CampFire @vicenews"

Overall, the spike on November 11 mainly represent several tweets and retweets of missing people. As time passes, the activity on Twitter reduced. However, on November 25, tweets with full names of missing and found people suddenly picked up. This was due to the sharing of missing and found people list by Sheriff around those days.

Several spikes appear on the right-side plot of the figure 2, which shows the distribution of tweets and retweets containing partial names. These spikes also reveal many important but similar updates[3] as in the case of the tweets with full names. However, we observe that partial names filter bring more noise than the full name filter. Hence, we recommend officials and automated system developers to first focus on analyzing tweets containing full names, as during a disaster situation both time and resources are usually scarce.

Trends related to the hashtags

Another convenient way to find updates about a specific topic on Twitter is through hashtags. Figure 3 shows the day-wise distributions of the tweets containing one of the missing hashtags (left-side plot) and found hashtags (right-side plot) from our selected hashtags.

In the case of missing hashtags, a big spike appears on November 12 followed by three, comparatively, small spikes on November 16, 18, and 25. On November 12, the following tweet from a daughter about her missing mother received several retweets.

"#Paradise #ParadiseFire #ParadiseLost #ParadiseEvacuees My mother lives in Magalia and I have not heard from her since the Camp Fire in Paradise started. We are searching all the shelters from Sac to Chico. Please share this post and pray that we can find her"

The tweet contains several hashtags, which is one of the reasons it reached to a broader audience. However, we found it using the `#ParadiseLost` hashtag. The tweet text does not contain the name of the missing person, however the name and a contact number are given in a photo attached to the tweet. Such cases signify the importance of analyzing other content types such as images, however this work only focuses on textual content analysis.

We observe several tweets about missing and found pets on the days with high tweets activity. People used different hashtags such as `#CALostCats, #LostPet, #MissingPet`, etc. to report about missing or found pets. Moreover, a large number of tweets found to give suggestions to the families of missing people to particular hashtags or follow particular Twitter users as doing so may help find their loved ones quickly. For instance, look at this tweet which suggests to follow the Twitter account of James Woods[4], a Hollywood star. "Please follow @RealJamesWoods as he helps find the missing lost in the CalifornaiaWildfires use hashtags..."

During the wildfires, James Woods, through his Twitter account, invited people to use the hashtags `#CampFireJamesWoods` and `#SoCalFiresJamesWoods` to post the names of missing family members and friends. He then shares the

[3]Notice that we omit several details due to the space limitations
[4]https://en.wikipedia.org/wiki/James$_{W}oods$

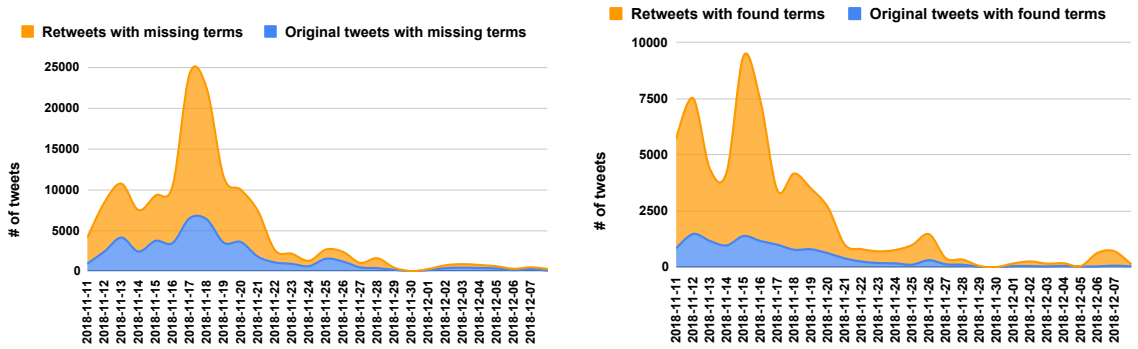


Figure 4. Distribution of original tweets and retweets with missing related keywords/terms (left) and with found related keywords/terms (right)

message to his more than 2 million followers. The following tweet was posted by James about lost horses, which were later found.

`She needs help with five horses. It was previously reported that her horses had been evacuated, but she says that did not happen. Please contact her at @Alyssa_Milano to get her location or use my hashtag #SoCalFiresJamesWoods This is a serious request.`

Another observation is that the tweets selected using hashtags contain more noise than the tweets selected using people names (as described above). For instance, many tweets containing missing or found-related hashtags, appear to provide general updates about this issue, e.g., see this tweet: `“More than 200 still missing in California’s deadliest wildfire on record blaze..."`

Moreover, many irrelevant tweets were found in which one of the relevant hashtags is used, but the tweet content is not related to the missing or found context.

Trends related to the terms

Figure 4 shows the day-wise distributions of the tweets and retweets obtained from the keyword-based filter.

One obvious observation, which is also consistent with names and hashtags trend analysis, is that the frequency of retweets increases with an increase in the frequency of original tweet. Several spikes emerged in both of the plots. In the case of missing-terms (left-side plot), spikes on November 13, 17, 18, 25, and 28 are visible. The largest activity was recorded between November 17 and 18 when 25k tweets were posted.

The tweets selected using keywords/terms contain more noise than the tweets selected using the names and hashtags. Terms such as “heard, safe, and contact" retrieved more off-topic results. Moreover, the term “Update" observed to retrieve tweets with general updates about casualties, damages, and missing people. However, rest of the terms yield many relevant results.

On November 13, we observe many general updates about various issues such as reports of deaths, ongoing humanitarian and search activities, reports of missing people and pets. Below are a few tweets from this day.

T1: `“RT @blkahn: BREAKING: The Camp Fire is officially the most deadly fire in California history. 42 dead, hundreds still missing"`
T2: `“BSG Teams search for bodies in California after wildfire claims 42 lives"`
T3: `“As of yesterday the death toll of CampFire has risen to 42, with more than 200 people still missing"`

During November 17 and 18, which is the period with largest Twitter activity, many tweets report about the increase in the winds. The Santa Ana winds gained much higher speed, resulting in spread of fire, and increase in casualties. We show a few related tweets below.

T1: `“California fires: death toll rises to 76 as winds threaten efforts to control blaze .wow. From 700 missing yesterday to 1300 now.“`
T2: `“At least 44 people are dead and more than 200 remain missing as two massive wildfires, fueled by easterly winds and a historic drought, continue to rage in California."`
T3: `“As the death toll and number of missing people rises, firefighters in Northern California are`

bracing for strong winds that could erode the progress they made on the deadliest fire in the country in at least a century."
T4: "RT @CTVNews: California fire latest: 76 dead, 1,300 missing and strong winds causing concern"

Furthermore, two relatively small spikes appear on November 25 and 28. Tweets posted on November 25 mainly contain general updates about the event, victims, and a few referring to people who are still not accounted for. However, many observed as less relevant to the context of missing and found people.

T1: "although the fires are contained the search for missing individuals continues hope this will be the last of these.."
T2: "authorities are still struggling to find human remains in magalia california after the horrible wildfire"

Figure 4 (right-side plot) shows the distribution of tweets containing any found-related terms. We observe spikes on November 12, 15, 16, 18, 26, and between December 6 and 7. On these days, again we observed many tweets reporting general updates about death toll, number of missing people, and showing their concerns. On November 12, a tweet giving general updates: "RT @stacos: BREAKING UPDATE: Death Tolls rise to 31, and hundreds still missing in California Wild Fire". On November 15 a tweet with updates: "California's deadliest fire: 13 more victims remains found ..".

Mostly tweets on November 16 and 18 talk about deceased and people who are still missing. Below are few examples.
T1: "At least 63 are now dead from the Camp Fire in Paradise, Calif. Officials say they have a missing persons list"
T2: "According to the Butte County Sheriff, an additional five human remains were found on Saturday, four in Paradise"
T3: "RT @DailyMail: At least 74 people have died in California wildfires as more than one thousand people are feared missing"

Many irrelevant tweets were found on November 26, December 6 and 7. Some generally discuss the event, victims, and response efforts from officials.

DISCUSSION & FUTURE WORK

This work analyzed the Twitter data posted during the 2018 California wildfires to investigate the types of information shared related to the issue of missing and found people. The analysis revealed that the tweets posted during the event contain important information in the forms of full names, partial names, locations, etc. about the missing and found people.

Around 400 tweets were found containing full names and about 300k tweets with partial names of potentially missing and found people. However, tweets with full names were found on-topic and considered more relevant to this issue compared to the tweets with partial names. Many partial names search retrieved tweets containing famous people names such as Donald Trump and other celebrities. The analysis revealed that people share names with different spellings, perhaps due to reasons such as interpreting and writing using phonetic knowledge, misspellings, typos, and sometimes using the auto-correct feature in mobiles. Officials and emergency managers can use tweets with names to help find missing people.

Furthermore, tweets selected using the related hashtags contain less noise than the tweets selected using the keywords/terms. Tweets of missing or found people with popular hashtags likely to receive more retweets. Moreover, tweets mentioning a famous Twitter user, as seen in the case of James Woods in this study, help spread the message quickly. The hashtags trend analysis revealed that many tweets report a missing person without explicitly mentioning a name. However, sometimes the names are found in an attached photo. Both hashtags and terms tweets contain general updates such as death toll, missing people count.

Although, our analysis revealed that Twitter contains useful information about the issue of missing and found people, performing manual analysis to identify relevant tweets is not a feasible option due to the sheer volume of data on Twitter. Therefore, we suggest developing or extending existing systems (e.g., AIDR (Imran, Castillo, Lucas, et al. 2014)) which can process and classify data in real-time to predict whether a tweet is about missing or found people issue or not. Moreover, automated solutions and systems to automatically detect tweets with names and locations, e.g., using named-entity recognition techniques need to be developed. Furthermore, we remark that incorporating images shared on social media related to the issue of missing and found people can substantially help concerned authorities to find missing people. Automatic image processing for this purpose would need extending existing techniques in this domain e.g., (Nguyen, Alam, et al. 2017; Alam, Imran, et al. 2017). We aim to work on these directions and develop needed solutions in the future.

CONCLUSIONS

This work analyzed Twitter data shared during the 2018 California wildfire event to investigate whether family and friends share information about their missing loved ones and whether that information can assist officials finding those missing people. Various filtering techniques were employed to select potentially relevant data. Moreover, a trend analysis of around 300k tweets was performed to investigate large activities during the timeline of the event manually. The analysis revealed that indeed Twitter contains various types of useful information about missing and found people. The study found that tweets containing the names of missing and found people, their last known locations, how they look like, etc. can provide vital clues to official responders to mitigate the issue of missing people. However, to achieve this goal, automatic systems need to be developed, which we consider as a future work.

REFERENCES

Acar, A. and Muraki, Y. (2011). "Twitter for crisis communication: lessons learned from Japan's tsunami disaster". In: *International Journal of Web Based Communities* 7.3, pp. 392–402.

Alam, F., Imran, M., and Ofli, F. (2017). "Image4act: Online social media image processing for disaster response". In: *Proceedings of the 2017 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining 2017*. ACM, pp. 601–604.

Alam, F., Ofli, F., and Imran, M. (2018). "Processing Social Media Images by Combining Human and Machine Computing during Crises". In: *International Journal of Human Computer Interaction* 34.4, pp. 311–327.

Castillo, C. (2016). *Big Crisis Data*. Cambridge University Press.

Heverin, T. and Zach, L. (2010). "Twitter for city police department information sharing". In: *Proceedings of the American Society for Information Science and Technology* 47.1, pp. 1–7.

Hunt, L. A., Brown, A. E., and Gilman, I. P. (2010). "Drivers with dementia and outcomes of becoming lost while driving". In: *American Journal of Occupational Therapy* 64.2, pp. 225–232.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015). "Processing social media messages in mass emergency: A survey". In: *ACM Computing Surveys* 47.4, p. 67.

Imran, M., Castillo, C., Lucas, J., Meier, P., and Vieweg, S. (2014). "AIDR: Artificial intelligence for disaster response". In: *ACM International Conference on World Wide Web*, pp. 159–162.

Kirkman, A. M. (2006). "Dementia in the news: the media coverage of Alzheimer's disease". In: *Australasian Journal on Ageing* 25.2, pp. 74–79.

Lindsay, B. R. (2011). *Social media and disasters: Current uses, future options, and policy considerations*.

Nguyen, D. T., Alam, F., Ofli, F., and Imran, M. (2017). "Automatic image filtering on social networks using deep learning and perceptual hashing during crises". In: *arXiv preprint arXiv:1704.02602*.

Nguyen, D. T., Joty, S., Imran, M., Sajjad, H., and Mitra, P. (2016). "Applications of online deep learning for crisis response using social media information". In: *arXiv preprint arXiv:1610.01030*.

Rosser, J. F., Leibovici, D., and Jackson, M. (2017). "Rapid flood inundation mapping using social media, remote sensing and topographic data". In: *Natural Hazards* 87.1, pp. 103–120.

Rowe, M. A., Vandeveer, S. S., Greenblum, C. A., List, C. N., Fernandez, R. M., Mixson, N. E., and Ahn, H. C. (2011). "Persons with dementia missing in the community: Is it wandering or something unique?" In: *BMC geriatrics* 11.1, p. 28.

Starbird, K., Palen, L., Hughes, A. L., and Vieweg, S. (2010). "Chatter on the red: what hazards threat reveals about the social life of microblogged information". In: *ACM Conference on Computer Supported Cooperative Work*, pp. 241–250.

Tsoi, K. K., Chan, N. B., Chan, F. C., Zhang, L., Lee, A. C., and Meng, H. M. (2018). "How can we better use Twitter to find a person who got lost due to dementia?" In: *npj Digital Medicine* 1.1, p. 14.

Vieweg, S., Hughes, A. L., Starbird, K., and Palen, L. (2010). "Microblogging during two natural hazards events: what twitter may contribute to situational awareness". In: *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, pp. 1079–1088.

Wang, Z., Ye, X., and Tsou, M.-H. (2016). "Spatial, temporal, and content analysis of Twitter for wildfire hazards". In: *Natural Hazards* 83.1, pp. 523–540.

Comparison of Social Media in English and Russian During Emergencies and Mass Convergence Events

Fedor Vitiugin
Independent

Carlos Castillo
Universitat Pompeu Fabra

ABSTRACT

Twitter is used for spreading information during crisis events. In this paper, we first retrieve event-related information posted in English and Russian during six disasters and sports events that received wide media coverage in both languages, using an adaptive information filtering method for automating the collection of about 100 000 messages. We then compare the contents of these messages in terms of 17 informational and linguistic features using a difference in differences approach. Our results suggest that posts in each language are focused on different types of information. For instance, almost 50% of the popular people mentioned in these messages appear exclusively in either the English messages or the Russian messages, but not both. Our results also suggest differences in the adoption of platform mechanics during crises between Russian-speaking and English-speaking users. This has important implications for data collection during crises, which is almost always focused on a single language.

Keywords

Social Media, Crisis Informatics, Twitter, Information Extraction.

INTRODUCTION

Over the last decade there has been increased interest in the use of social media for disaster communication. A wide range of studies suggests that information sharing networks, such as Twitter, can be very useful in times of crisis due to quick and effective dissemination of relevant news (Yin et al. 2015). Previous works have used quantitative data collection methods and focused on strategic keyword detection (Corvey et al. 2010), a perception of false RTs (Mendoza et al. 2010), and categorization of the tweets sent during disasters (Olteanu, Vieweg, et al. 2015; Öztürk and Ayvaz 2018), among many other topics (Castillo 2016). Most previous works considered tweets in English (Reuter, Hughes, et al. 2018; Reuter, Backfried, et al. 2018), with some exceptions (Zielinski et al. 2012; Doan et al. 2011). In general, messages are collected for emergency response or research purposes in a single language.

This study aims to characterize the differences between messages posted in English and Russian in social media during the same events. Specifically, we seek to address differences in the information conveyed (e.g., mentions of persons, organizations, and locations) and in the linguistic characteristics of messages shared (e.g., parts of speech being used). We ground these differences in "background" collections done in both languages during periods without events, which allows us to use a difference-in-differences approach to quantify changes.

Intuitively, one could assume that collecting data about a crisis in multiple languages should yield more information that using a single language. In this paper, we try to quantify how much is lost by doing a single-language data collection. Our aims in this research are:

- to create a method for finding, collecting and filtering relevant data in Twitter about crises in several languages;
- to create event-driven parallel datasets of events across languages;
- to identify the most significant features for the comparison of tweets across languages;
- to compare the information and linguistic characteristics of these datasets.

LITERATURE REVIEW

Social media has become one of the main sources of communication and information during crisis situations, including disasters and mass convergence events. Using computational methods from many disciplines (Castillo 2016) helps to build systems that can help emergency managers during real crises.

Disasters in Social Media

Modern disaster management processes can use social media technologies to capture event parameters, to help effective decision making, and to share knowledge (Yates and Paquette 2010).

The information in social media during a disaster depends on different factors. For instance, during Japan's tsunami in 2011, people in directly affected areas tended to post about their unsafe and uncertain situation, while people in remote areas posted messages to let their followers know that they were safe (Acar and Muraki 2011). Systematic examinations of a diverse set of crises has uncovered substantial variability across crises, as well as patterns and consistencies across dimensions such as informativeness, information type, and source (Olteanu, Vieweg, et al. 2015).

Languages in Twitter

In most research using Twitter data, the natural tendency has been to assume that the behaviors of English users generalize to other language users (Olteanu, Castillo, et al. 2016). However, given the widespread adoption of Twitter internationally, some researchers have investigated the differences among users of different languages. Examining users of the top 10 languages and general messages (not topic-specific), cross-language differences in adoption of features such as URLs, hashtags, mentions, replies, and retweets have been described (Hong et al. 2011). Regarding news media, the linguistic properties of tweets of selected English and German daily newspapers have been analyzed to identify the structural, discursive and rhetorical goals of newspaper tweets (Tereszkiewicz 2013).

This type of cross-lingual comparison has many challenges, including detecting different nationalities (Laboreiro 2018). However, it can also be very useful to help build models and tools for detecting differences in societal priorities, people's behavioral factors, social, economic, and environmental performances (Resce and Maynard 2018).

Multilingual users are very prevalent in Twitter (Hale 2014), indeed, there is a large interest within the research community on multilingual texts in Twitter and the interaction of multilingual users in the network (Papalexakis and Doğruöz 2015).

In addition to language, a further axes for comparative social media analysis are location and platform. Distance and related variables (language, country, and the number of flights) all have an effect on Twitter ties despite the substantial ease with which long-range ties can be formed (Takhteyev et al. 2012) There are also significant differences across platforms, e.g., in the microblogging behavior on Sina Weibo and Twitter. These provide valuable insights for multilingual and culture-aware user modeling based on user's behavior, microblogging syntactic, semantic and sentiment data (Gao et al. 2012).

In contrast to the previous works, our contribution is that we focus on changes during crisis events, which can be very varied but almost invariably leave a large footprint in social media communities. We compare multiple events in two languages: English and Russian, and our proposed research methodology includes not only an analysis of the linguistics characteristics of messages, but also of the informativeness of messages and their sources, and virality.

DATA COLLECTION AND FILTERING

In this section, we discuss our approach for collecting data: an Adaptive Information Filtering approach based on locations, which helps in the detecting new keywords and collect relevant data. After that, we briefly describe the classification model that helps us automate dataset creation for further analysis.

Overview

For data collection, we build a processing pipeline (Figure 1) that starts with a seed set of location-based keywords (place names) for real-time filtering of tweets and captures messages about an event that happens in the specified location(s). Public tweets were collected and stored independently by language using Twitter's public API. Next, we use an algorithm based on TF-IDF (Ramos et al. 2003) for gathering new keywords for searching and continuing

collecting messages. All tweets with keywords mentions were filtered by an automated classifier (Aggarwal and Zhai 2012) based on hand-labeled samples of data to obtain the final lists of tweets for analysis.

We used standard text data preprocessing and extracted informational and linguistic features. The final stage of the analysis was the difference in differences comparison (Abadie 2005) that shows similarities and differences of short-text messages between "normal" and crisis situations in Russian and English.

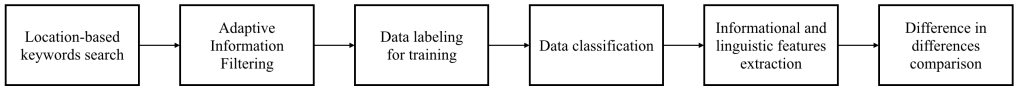


Figure 1. Pipeline of research system

The main challenge for collecting data that we faced is availability large events receiving wide media coverage in both languages, which already hints that information in Twitter in both languages might be quite different. Many large events were discussed quite prominently through tweets in English but were much less talked about in Russian tweets, and vice-versa.

Adaptive Information Filtering

The primary task of Adaptive Information Filtering is to reduce a user's information load with respect to his or her interest described by a request. The filter is supposed to correctly filter an incoming stream, such that relevant keywords are added to adapt the request described by the user. Thus, adaptive information filtering can be described as a type of unsupervised classification problem which must detect new topics in the incoming stream. The objective of our task is similar to the task of topic detection and tracking (TDT) (Allan et al. 1998). TDT is defined as an unsupervised learning problem. There are no relevance classes with respect to a particular user interest. The primary interest is to detect the occurrence of changes as early as possible. Once new topics have been detected, the tracking of new topics must be corrected.

In our implementation, the initial user's query contains only location keywords (district, city, country) which are related to the event. Through the Twitter API we perform a request for collecting public tweets in the stream which contain these keywords. When the number of messages collected surpasses a threshold, all collected documents processed by the Adaptive Information Filtering (AIF) model.

The first stage of our AIF implementation is a pre-processing stage, which starts with language detection. We use the standard Twitter API language parameter for this. After this stage, we had two datasets in different languages — Russian and English. All documents in every message are preprocessed — texts tokenization, deleting special symbols which are used in Twitter for mentions, hashtags, etc., and lemmatization because of in Russian language stemming shows lower efficiency for pre-processing texts (Jivani et al. 2011). Then, every document becomes a bag of words represented using the Vector Space model (Salton and McGill 1986). The vectors are built during the initial phase from the corpus created based on the request from the user.

After lemmatization, every text document is transformed into a list of words without functional words (also known as a stoplist). The words are weighed by the standard $TF - IDF$ product, with TF is the term frequency in the document, and $IDF = log(n/DF(i))$ with n the number of documents in the collection and $DF(i)$ the number of documents in the collection who contain the word i (Marinilli et al. 1999). Then we chose the L most popular terms in the collection, where L is set heuristically to 4 terms based on initial experiments. The new query contains terms which were chosen in the previous step. After the number of messages in the new query becomes the same as the threshold parameter, all new documents are again processed by our AIF-model. All documents in all queries are collected into one dataset which contains filtered tweets connected with the specified event.

The AIF-model approach allows capturing the data variability and collecting more informative data by adding new keywords and new threads which connected with the event.

Classification model

The messages we capture using the procedure described above include many messages that are not related to any specific event of our interest. Hence, the next step for creating the datasets is building a classification model for filtering tweets that are contain information about an event, excluding other information that is not related to an

event but is nevertheless captured by the data collection process. This task can be described as an supervised, binary classification problem.

We compared several learning schemes (Support vector machine, Stochastic gradient descent, Extremely randomized trees), based on word embeddings (similarly to (Wijeratne et al. 2016)). We first create words embeddings for every social media message with the help of the doc2vec embeddings model (Le and Mikolov 2014), which is well suited for short length text and outperforms the word2vec model and probabilistic latent semantic analysis model approach, as discussed in (Gupta, Abhinav, et al. 2013; Nguyen et al. 2016; Khosla et al. 2017). Now, each of the word embedding combines another feature vector which was formed using the frequency of each term available in a tweet. After preprocessing, we have one entire embedding vector of length 300 which will be the final representative of the respective class.

Social media tweets in our collections are transformed into vectors (each of length 300) in which the absence of most similar tweets are ensured. These embeddings will be the input for training models.

Training data includes two labeled collections of sport events containing 6 000 tweets and 3 000 tweets respectively, with 20% of tweets for testing and 80% for training. We use a batch-based online learning method with batch size equals 300.

During the training of the Random Forest model, entire training embedding vectors were cross-validated with K-folds (k=10), and showed maximum precision and recall in comparison with Support vector machine, Stochastic gradient descent, Extremely randomized trees, including F-Score (Table 1).

Table 1. Results of learning schemes comparison

	Precision	*Recall*	*F1*
RandomForest	**0.9022**	0.7339	**0.8079**
LinearSVM	0.8747	**0.7407**	0.8019
SGD	0.8819	0.6679	0.7550
ExtraTrees	0.8393	0.6372	0.7243

For our research we considered six events from September to December 2018 that were widely covered in both English and Russian in Twitter. Four of these events are disasters, while the remaining two are worldwide sports events with a significant footprint in social media in both languages. The amount of data collected, before filtering and after filtering using the AIF approach above and for each event is listed on Table 2.

Table 2. Collected data

		Number of tweets before filtering		Number of tweets after filtering	
Events	*Dates*	*English*	*Russian*	*English*	*Russian*
Anchorage Earthquake	01.12.18 — 03.12.18	36,865	1,263	26,691	1,082
Ebeko Volcano Activities	02.11.18 — 06.11.18	67,000	1,500	2,595	258
Kerch Poly Massacre	18.10.18 — 20.10.18	1,850	3,350	1,267	1,358
Paris Fuel Riot	24.11.18 — 26.11.18	163,345	2,344	64,385	676
F1 Race in Sochi	30.09.18 — 04.10.18	333	1,650	102	189
UFC229 Khabib vs Connor	05.10.18 — 07.10.18	650	600	267	190

EXTRACTION OF CONTENT FEATURES

Primarily, the motivation for this paper is to compare the informativeness of crisis tweets across languages. To quantify the extent to which information in each language is unique, we focus on Named Entities, which include:

- persons — these features consider mentions of people by users in their messages. Empirically they are typically politicians, celebrities or people directly affected by an event;
- locations — this feature considers mentions of places in their messages e.i. city, district, state etc.;

- organizations — this feature considers mentions of government or non-governmental organizations, for-profit companies, or other organizations or associations;
- time references — this feature considers time and time interval mentions.

In addition to named entities, we considered other features which are stylistic or refer to platform mechanics:

- type of account — it shows relation between regular users and verified i.e. accounts of politics, celebrities, media or another organizations;
- usage of links in texts — shows if the message is full or is it just a teaser of another material or petition;
- usage of numbers — this feature shows how much facts the message contains because digits/numbers are the main feature of fact in text;
- usage of quotes — this feature shows how much times users cite another person, direct participant of event or expert in disaster;
- dialogues (or @mentions) — it shows how much times Twitter users entered into a dialogue with another user;
- number of retweets — this shows how many times the message was re-posted in Twitter and is related to the relevance of the message for Twitter's community;
- usage of hashtags — exposure desire of an author come into trend connected with event.

The last group of features which were analyzed during this paper are part-of-speech elements, including:

- verbs — typically indicates actions described by users in their tweets;
- nouns — typically describes a variety of elements and objects that participate in those actions.

While extracting these features we were faced several complexities connected with language differences. For each of the two languages we created a separate analytics pipeline included linguistic resources (dictionary of stopwords, special symbols), morphological parser for POS-detection (Russian — pymorphy2[1] Python library, English — Python NLTK[2] pos-parser), Named Entities parsers (Russian — natasha[3] Python library, English — SpaCy[4] Python library).

RESULTS

Based on datasets we evaluated tweets for the purpose of detecting differences. The filtered datasets were used for comparison against the control group (regular Russian and English tweets collected while no large event was happening; 10 000 in both cases) and get the difference in differences (DD) index.

For calculating average DD for feature (example — persons in English tweets) at first we calculate feature values for every event. Then we calculate DD index for every event by the difference between the values during the event and during the general stream: $DD_{event} = value_{event} - value_{general}$. After that we calculate average value of DD for feature: $DD_{avarage} = (DD_{event}1 + DD_{event}2 + \ldots + DD_{event}n)/n$.

For calculating median DD for feature we also use DD indexes for every event: DD_{median} equals mean of the two middle values in the ordered row of DD_{event}. DD_{median} helps us to get "typical" value if some of DD_{event} values are extremely large or small.

In the tables we mark with an "*" in the English column cases where the $DD_{average}$ in English is larger than the $DD_{average}$ in Russian by more than one standard deviation among the different events as captured in Russian. Conversely, we mark with an "*" in the Russian column cases where $DD_{average}$ in Russian is larger than $DD_{average}$ in English by more that one standard deviation among the different events as captured in English.

[1]https://pymorphy2.readthedocs.io/
[2]https://www.nltk.org/
[3]https://github.com/natasha/natasha
[4]https://spacy.io/

Entities

During analysis of named entities we get interesting results that illustrate differences in Russian and English tweets published during disasters (Table 3). Both languages mention a similar number of person entities in the background collection, but during events these numbers similarly increase/decrease, depending on the types of event. During sport events and human-made crises we see more person entities, but during natural disasters this number decreases.

Table 3. Named entities analysis results. The "*" marks statistics for the Russian messages that differ by more than one standard deviation from the English messages.

	DD Average	*DD Median*
Av. persons in English tweet	0.0941	-0.0473
Av. persons in Russian tweet	**0.1133**	**0.0599**
Av. locations in English tweet	0.6708	0.6859
Av. locations in Russian tweet	**0.9021**	**0.8418**
Av. organizations in English tweet	**0.2549***	**0.1649***
Av. organizations in Russian tweet	0.0204	0.0148
Av. unique persons in English tweet	-0.0559	-0.0999
Av. unique persons in Russian tweet	**-0.0394**	**-0.0714**
Av. unique locations in English tweet	-0.0148	**-0.0122**
Av. unique locations in Russian tweet	**-0.0131**	-0.0332
Av. unique organizations in English tweet	-0.0868	-0.0659
Av. unique organizations in Russian tweet	**-0.0118**	**-0.0286**

During the analysis of the most mentioned persons (Table 4) we find that more than half (52,5%) of top-5 named entities in both languages are the same (Figure 2).

Table 4. Exclusive entities in top-5 distribution

	Exclusive English	*English and Russian*	*Exclusive Russian*
Persons	55%	42%	62%
Locations	43%	50%	50%
Organizations	86%	9%	76%

Texts in Russian language contain more location entities and this variable also increases during all types of events. We obtain opposite results for the number of organizations entities — their number in Russian tweets is lower in the background collection and remains lower during all types of events. These observations can be connected with Russian-speaking users who prefer to know more about where something happens but not interested in who made it happen.

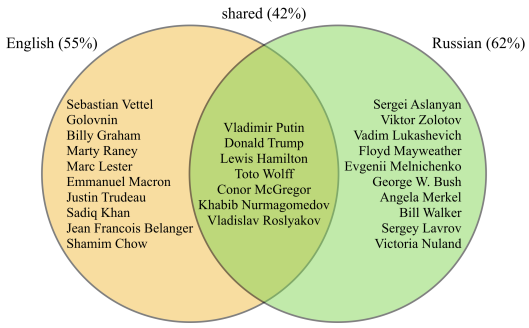


Figure 2. Persons entities distribution

Links and citations

In regular periods (background collection) tweets in Russian contain more links compared with tweets in English. But analysis of events shows this is reversed — Russian-speaking users prefer to share their own impressions, not to spread links (which come mostly from news and similar sites), while the number of links in English tweets usually increases. Tweets in both languages contain a lower number of citations during events than in regular time (Table 5).

Table 5. Links and citations analysis results

	DD Average	*DD Median*
Usage of links (number) in English	**0.4569**	**0.4747**
Usage of links (number) in Russian	0.2194	0.2649
Usage of citations in English	-0.0174	-0.0312
Usage of citations in Russian	**-0.0053**	**-0.0053**

Part of speech

For analysis we choose just nouns and verbs as informative parts of speech for our purposes (Langacker 1987). Part of speech analysis revealed that Russian-speaking users more often use verbs in regular tweets, but during disasters the number of verbs decreases. Actions in crises for Russian-speaking community are less often included in messages. On the other hand, the number of nouns in Russian tweets during events increases (Table 6).

Table 6. Part of speech analysis results. The "*" means a different of more than one standard deviation.

	DD Average	*DD Median*
POS-parsing (verbs) in English	-0.2891	-0.3262
POS-parsing (verbs) in Russian	**-0.0790***	**-0.2899**
POS-parsing (nouns) in English	-0.2247	0.0433
POS-parsing (nouns) in Russian	**0.8731***	**0.8810**

Platform mechanisms

Analysis of platform mechanics including as mentions, retweets, hashtags, and account verification shows that English-speaking users are more familiar with them than Russian-speaking users (Table 7). During events, verified accounts become more active. This is due to the activation of media — more news, analysis, and expert opinions about what happened. This is clear during the Kerch Poly massacre, where the amount of English-speaking verified accounts is much bigger than Russian-speaking while the amount of mentions in English decreases (see Appendix Table 9). This confirms decreasing numbers of mentions and retweets in both languages because users prefer to share their own impressions.

Table 7. Platform mechanics analysis results. The "*" means a different of more than one standard deviation.

	DD Average	*DD Median*
Type of account (name, verification) in English	**0.0328**	0,0157
Type of account (name, verification) in Russian	0.0175	**0.0164**
Dialogue (usage of mentions) in English	-0.4657	**-0.4011**
Dialogue (usage of mentions) in Russian	**-0.3458**	-0.4484
Spreading information (usage of RT) in English	-0.3701	-0.5167
Spreading information (usage of RT) in Russian	**-0.1377**	**-0.4068**
Want to trend (usage of hashtags) in English	**0.2430***	**0.1821**
Want to trend (usage of hashtags) in Russian	-0.0017	-0.0146

Times, numbers

Tweets in Russian contains less temporal references and during events this number further decreases. It shows that Russian-speaking users use Twitter as a real-time platform, to speak about what is happening now. The number of numerical facts (tweets including numbers) is similar in both languages in background collection and during events is similarly increased or decreased, depending on the type of event (Table 8).

Table 8. Times and numbers analysis results. The "*" means a different of more than one standard deviation.

	DD Average	*DD Median*
Av. time reference in English tweet	**0.0160***	-0.0417
Av. time reference in Russian tweet	-0.0100	**-0.0048**
Av. unique time reference in English tweet	-0.0178	-0.0400
Av. unique time reference in Russian tweet	**-0.0053**	**-0.0065**
Usage of numbers (check of using numbers) in English	**0.3284**	**0.0855**
Usage of numbers (check of using numbers) in Russian	0.0660	0.0372

CONCLUSION, LIMITATIONS, AND FUTURE WORK

We have made the first step for comparison of informativeness in social media in English and Russian languages. We found that analyzing tweets about an event in two languages simultaneous can yield substantially more information than in only one language.

Our analysis of named entities allows to capture a larger number of locations (in Russian) and organizations (in English), as well as learning about more people associated with an event (almost 50% of popular people are exclusive to each language). The analysis of messages in Russian indicates an increase in the information content through a decrease in the use of links and quotations, a simultaneous decrease in the number of verbs and an increase in the number of nouns. In future work, we plan to analyze the impact of these parameters on subjectivity in tweets. An analysis of messages in English language revealed the activation of verified accounts, as well as the use of numbers and time references.

Hence, the analysis of only English (or only Russian) tweets would miss a substantial amount of valuable data that can describe the effects of a crisis — detailed names of locations or new names of relevant persons. We will consider the size of the impact of this data in future work.

The main implication from this work is that collecting data in one language during a crisis means losing significant and relevant information. This can only be avoided by collecting information in several languages. While we have not analyzed the location of the users, we assume that users who write messages in the local language have more relevant information about a crisis, from relatives or local media, than users who write messages in other languages.

In the next steps of our research we will add more languages and concentrate in specific classes of disaster. We also plan to use more sophisticated classification models including convolutional neural networks (including LSTM) for filtering tweets that are relevant for an event.

REFERENCES

Abadie, A. (2005). "Semiparametric difference-in-differences estimators". In: *The Review of Economic Studies* 72.1, pp. 1–19.

Acar, A. and Muraki, Y. (2011). "Twitter for crisis communication: lessons learned from Japan's tsunami disaster". In: *International Journal of Web Based Communities* 7.3, pp. 392–402.

Aggarwal, C. C. and Zhai, C. (2012). "A survey of text classification algorithms". In: *Mining text data*. Springer, pp. 163–222.

Allan, J., Carbonell, J. G., Doddington, G., Yamron, J., and Yang, Y. (1998). "Topic detection and tracking pilot study final report". In:

Castillo, C. (2016). *Big crisis data: social media in disasters and time-critical situations*. Cambridge University Press.

Corvey, W. J., Vieweg, S., Rood, T., and Palmer, M. (2010). "Twitter in mass emergency: what NLP techniques can contribute". In: *Proceedings of the NAACL HLT 2010 Workshop on Computational Linguistics in a World of Social Media*. Association for Computational Linguistics, pp. 23–24.

Doan, S., Vo, B.-K. H., and Collier, N. (2011). "An analysis of Twitter messages in the 2011 Tohoku Earthquake". In: *International Conference on Electronic Healthcare*. Springer, pp. 58–66.

Gao, Q., Abel, F., Houben, G.-J., and Yu, Y. (2012). "A comparative study of users' microblogging behavior on Sina Weibo and Twitter". In: *International Conference on User Modeling, Adaptation, and Personalization*. Springer, pp. 88–101.

Gupta, N., Abhinav, K., et al. (2013). "Fuzzy sentiment analysis on microblogs for movie revenue prediction". In: *Emerging Trends in Communication, Control, Signal Processing & Computing Applications (C2SPCA), 2013 International Conference on*. IEEE, pp. 1–4.

Hale, S. A. (2014). "Global connectivity and multilinguals in the Twitter network". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, pp. 833–842.

Hong, L., Convertino, G., and Chi, E. H. (2011). "Language Matters In Twitter: A Large Scale Study." In: *ICWSM*, pp. 518–521.

Jivani, A. G. et al. (2011). "A comparative study of stemming algorithms". In: *Int. J. Comp. Tech. Appl* 2.6, pp. 1930–1938.

Khosla, P., Basu, M., Ghosh, K., and Ghosh, S. (2017). "Microblog retrieval for post-disaster relief: Applying and comparing neural ir models". In: *arXiv preprint arXiv:1707.06112*.

Laboreiro, G. A. T. (2018). "Noise reduction and normalization of microblogging messages". In:

Langacker, R. W. (1987). "Nouns and verbs". In: *Language*, pp. 53–94.

Le, Q. and Mikolov, T. (2014). "Distributed representations of sentences and documents". In: *International Conference on Machine Learning*, pp. 1188–1196.

Marinilli, M., Micarelli, A., and Sciarrone, F. (1999). "A case-based approach to adaptive information filtering for the WWW". In: *Proceedings of the TUE Computing Science Report* 99.07.

Mendoza, M., Poblete, B., and Castillo, C. (2010). "Twitter Under Crisis: Can we trust what we RT?" In: *Proceedings of the first workshop on social media analytics*. ACM, pp. 71–79.

Nguyen, D. T., Joty, S., Imran, M., Sajjad, H., and Mitra, P. (2016). *Applications of Online Deep Learning for Crisis Response Using Social Media Information*. arXiv: 1610.01030 [cs.CL].

Olteanu, A., Castillo, C., Diaz, F., and Kiciman, E. (2016). "Social data: Biases, methodological pitfalls, and ethical boundaries". In:

Olteanu, A., Vieweg, S., and Castillo, C. (2015). "What to expect when the unexpected happens: Social media communications across crises". In: *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*. ACM, pp. 994–1009.

Öztürk, N. and Ayvaz, S. (2018). "Sentiment analysis on Twitter: A text mining approach to the Syrian refugee crisis". In: *Telematics and Informatics* 35.1, pp. 136–147.

Papalexakis, E. and Doğruöz, A. S. (2015). "Understanding multilingual social networks in online immigrant communities". In: *Proceedings of the 24th International Conference on World Wide Web*. ACM, pp. 865–870.

Ramos, J. et al. (2003). "Using tf-idf to determine word relevance in document queries". In: *Proceedings of the first instructional conference on machine learning*. Vol. 242, pp. 133–142.

Resce, G. and Maynard, D. (2018). "What matters most to people around the world? Retrieving Better Life Index priorities on Twitter". In: *Technological Forecasting and Social Change* 137, pp. 61–75.

Reuter, C., Backfried, G., Kaufhold, M.-A., and Spahr, F. (2018). "ISCRAM turns 15: A Trend Analysis of Social Media Papers 2004-2017". In: *Proceedings of the 15th ISCRAM conference*.

Reuter, C., Hughes, A. L., and Kaufhold, M.-A. (2018). "Social media in crisis management: An evaluation and analysis of crisis informatics research". In: *International Journal of Human–Computer Interaction* 34.4, pp. 280–294.

Salton, G. and McGill, M. J. (1986). "Introduction to modern information retrieval". In:

Takhteyev, Y., Gruzd, A., and Wellman, B. (2012). "Geography of Twitter networks". In: *Social networks* 34.1, pp. 73–81.

Tereszkiewicz, A. (2013). "Tweeting the news: a contrastive study of english and german newspaper tweets". In: *kwartalnik neofilologiczny* 3.

Wijeratne, S., Balasuriya, L., Doran, D., and Sheth, A. (2016). "Word embeddings to enhance twitter gang member profile identification". In: *arXiv preprint arXiv:1610.08597*.

Yates, D. and Paquette, S. (2010). "Emergency knowledge management and social media technologies: A case study of the 2010 Haitian earthquake". In: *Proceedings of the 73rd ASIS&T Annual Meeting on Navigating Streams in an Information Ecosystem-Volume 47*. American Society for Information Science, p. 42.

Yin, J., Karimi, S., Lampert, A., Cameron, M., Robinson, B., and Power, R. (2015). "Using social media to enhance emergency situation awareness". In: *Twenty-Fourth International Joint Conference on Artificial Intelligence*.

Zielinski, A., Bügel, U., Middleton, L., Middleton, S., Tokarchuk, L., Watson, K., and Chaves, F. (2012). "Multilingual analysis of twitter news in support of mass emergency events". In: *EGU General Assembly Conference Abstracts*. Vol. 14. Citeseer, p. 8085.

APPENDIX

Table 9 includes all the statistics we have presented in a single view.

Table 9. Full analysis results of all events

	Regular	*Anchorage*	*DD Anchorage*	*Ebeko*	*DD Ebeko*	*Kerch*	*DD Kerch*	*Paris*	*DD Paris*	*F1*	*DD F1*	*UFC*	*DD UFC*
Av. persons in English tweet	0.2507	0.1664	-0.0843	0.1642	-0.0865	0.2032	-0.0475	0.2037	-0.047	0.7921	0.5414	0.5393	0.2886
Av. persons in Russian tweet	0.2617	0.2190	-0.0427	0.004	-0.2578	0.2380	-0.0239	0.4050	0.1436	0.4160	0.1540	0.9680	0.7067
Av. locations in English tweet	0.3736	0.3054	-0.0682	0.6876	0.3140	1.3347	0.9611	0.5601	0.1865	0.3663	-0.0073	0.5169	0.1433
Av. locations in Russian tweet	0.0700	0.002	-0.0681	0.0120	-0.0584	0.166	0.0957	0.0030	-0.0671	0.2020	0.1322	0.1580	0.0879
Av. organizations in English tweet	0.1890	0.1662	-0.0228	0.5832	0.3942	0.1283	-0.0607	0.2395	0.0505	0.0792	-0.1098	0.0337	-0.1553
Av. organizations in Russian tweet	0.0325	0.0320	-0.0002	0.0310	-0.0015	0.0300	-0.0023	0.0250	-0.0074	0.0110	-0.0213	0.0050	-0.0272
Av. time reference in English tweet	0.1890	0.1662	-0.0228	0.5832	0.3942	0.1283	-0.0607	0.2395	0.0505	0.0792	-0.1098	0.0337	-0.1553
Av. time reference in Russian tweet	0.0325	0.0320	-0.0002	0.0310	-0.0015	0.0300	-0.0023	0.0250	-0.0074	0.0110	-0.0213	0.0059	-0.0272
Av. unique persons in English tweet	0.1724	0.0418	-0.1306	0.0573	-0.1151	0.0876	-0.0848	0.0099	-0.1625	0.2178	0.0454	0.2846	0.1122
Av. unique persons in Russian tweet	0.1237	0.0150	-0.1089	0.0040	-0.1198	0.0900	-0.0339	0.0120	-0.1119	0,1910	0,0673	0.1950	0.0710
Av. unique locations in English tweet	0.0689	0.0223	-0.0466	0.0704	0.0015	0.0430	-0.0259	0.0048	-0.0641	0.1089	0.0400	0.0749	0.0060
Av. unique locations in Russian tweet	0.1140	0.0280	-0.0863	0.0500	-0.0636	0.1110	-0.0028	0.0330	-0.0815	0.1570	0.0433	0.2260	0.1123
Av. unique organizations in English tweet	0.2498	0.0777	-0.1721	0.1566	-0.0932	0.2112	-0.0386	0.0232	-0.2266	0.2772	0.0274	0.2322	-0.0176
Av. unique organizations in Russian tweet	0.0404	0.0020	-0.0386	0.0080	-0.0326	0.0760	0.0354	0.0030	-0.0374	0.0670	0.0270	0.0160	-0.0246
Av. unique time reference in English tweet	0.0777	0.0266	-0.0511	0.1825	0.1048	0.0454	-0.0323	0.0054	-0.0723	0.0693	-0.0084	0.0300	-0.0477
Av. unique time reference in Russian tweet	0.0124	0.0030	-0.0096	0.0160	0.0031	0.0070	-0.0058	0.0010	-0.0109	0.0110	-0.0012	0.0050	-0.0071
Type of account (name, verification) in English	0.0102	0.0145	0.0043	0.0255	0.0153	0.1131	0.1029	0.0094	-0.0008	0.0693	0.0591	0.0262	0.0160
Type of account (name, verification) in Russian	0.0059	0.0037	-0.0022	0.0166	0.0107	0.0279	0.0221	0	-0.0059	0.0449	0.0390	0.0474	0.0415
Usage of links (number) in English	0.4021	0.5114	0.1093	1.0120	0.6099	1.0629	0.6608	0.5986	0.1965	1.2277	0.8256	0.7416	0.3395
Usage of links (number) in Russian	0.4487	0.4778	0.0291	1.0581	0.6094	0.9065	0.4578	0.1391	-0.3096	0.7640	0.3153	0.6632	0.2145
Usage of numbers (check of using numbers) in English	0.2283	0.6648	0.4365	1.8880	1.6597	0.4988	0.2705	0.0849	-0.1434	0.1287	-0.0996	0.0749	-0.1534
Usage of numbers (check of using numbers) in Russian	0.2425	0.7348	0.4923	0.4884	0.2459	0.2224	-0.0201	0.0369	-0.2055	0.3371	0.0946	0.0316	-0.2109
Usage of citations in English	0.0447	0.0158	-0.0289	0.0073	-0.0374	0.0924	0.0477	0.0373	-0.0074	0	-0.0447	0.0112	-0.0335
Usage of citations in Russian	0.0053	0	-0.0053	0	-0.0053	0	-0.0053	0	-0.0053	0	-0.0053	0	-0.0053
Dialogue (usage of mentions) in English	1.0965	0.8548	-0.2417	0.4442	-0.6523	0.1514	-0.9451	0.9434	-0.1531	0.5743	-0.5222	0.8165	-0.2800
Dialogue (usage of mentions) in Russian	0.7876	0.8531	0.0655	0.0039	-0.7837	0.3152	-0.4724	0.9246	0.1369	0.1910	-0.5966	0.3632	-0.4244
Spreading information (usage of RT) in English	0.6933	0.6833	-0.0100	0.3029	-0.3904	0.0502	-0.6431	0.8894	0.1961	0.0099	-0.6834	0.0037	-0.6896
Spreading information (usage of RT) in Russian	0.4337	0.8226	0.3889	0	-0.4337	0.0538	-0.3799	0.8994	0.4657	0	-0.4337	0	-0.4337
Want to trend (usage of hashtags) in English	0.2724	0.4557	0.1833	0.9529	0.6805	0.5394	0.2670	0.4140	0.1416	0.2772	0.0048	0.4532	0.1808
Want to trend (usage of hashtags) in Russian	0.1429	0.0702	-0.0727	0.0349	-0.1080	0.2298	0.0869	0.2559	0.1130	0.1461	0.0032	0.1105	-0.0324
POS-parsing (verbs) in English	0.7929	0.5075	-0.2854	0.4259	-0.3670	0.2948	-0.4981	0.8573	0.0644	0.3267	-0.4662	0.6105	-0.1824
POS-parsing (verbs) in Russian	1.4528	1.0887	-0.3641	0.9651	-0.4877	1.1797	-0.2731	2.3210	0.8682	1.1461	-0.3067	1.5421	0.0893
POS-parsing (nouns) in English	5.4366	6.1311	0.6945	5.3423	-0.0943	5.6175	0.1809	5.8024	0.3658	3.3069	-2.1297	5.0712	-0.3654
POS-parsing (nouns) in Russian	4.2638	5.1580	0.8942	5.3423	1.0785	4.8004	0.5366	5.6361	1.3723	4.7528	0.4890	5.1316	0.8678

When Official Systems Overload: A Framework for Finding Social Media Calls for Help during Evacuations

Steve Peterson
National Institutes of Health
steve.peterson@nih.gov

Keri K. Stephens
University of Texas - Austin
keri.stephens@austin.utexas.edu

Amanda Hughes
Brigham Young University
Amanda_Hughes@byu.edu

Hemant Purohit
George Mason University
hpurohit@gmu.edu

ABSTRACT

During large-scale disasters it is not uncommon for Public Safety Answering Points (e.g., 9-1-1) to encounter service disruptions or become overloaded due to call volume. As observed in the two past United States hurricane seasons, citizens are increasingly turning to social media whether as a consequence of their inability to reach 9-1-1, or as a preferential means of communications. Relying on past research that has examined social media use in disasters, combined with the practical knowledge of the first-hand disaster response experiences, this paper develops a knowledge-driven framework containing parameters useful in identifying patterns of shared information on social media when citizens need help. This effort explores the feasibility of determining differences, similarities, common themes, and time-specific discoveries of social media calls for help associated with hurricane evacuations. At a future date, validation of this framework will be demonstrated using datasets from multiple disasters. The results will lead to recommendations on how the framework can be modified to make it applicable as a generic disaster-type characterization tool.

Keywords

Disasters, social media, hurricanes, data, framework, emergency response

INTRODUCTION

During the 2017 hurricane season, the United States experienced three major hurricanes of Category 4 or greater in less than two months. In August 2018, the Federal Communications Commission published a report on the 2017 Atlantic hurricane season and its impact on communications (Federal Communications Commission 2018). The report documented a disruption of service at 41 Public Safety Answering Points (PSAP) in six states and territories as a result of the three hurricanes. Examples of PSAP infrastructure disruptions included: completely out of service; unable to receive incoming calls; no location identifiers available on received calls; unable to re-route calls; and forced to re-route calls to administrative lines or another PSAP. When a primary means of reaching emergency response organizations fails, citizens resort to using social media as an alternative way to try to reach those organizations (Hughes et al. 2014), as well as publicly posting a message requesting help (Rhodan 2017). However, there are several problems in efficiently collecting these requests by emergency response organizations. For instance, in flooding situations—like those resulting from recent hurricanes in the U.S.—the challenge is that as citizens turn to social media to request evacuation help, official emergency response organizations have limited knowledge or experience of information processing in this new media environment (Hiltz et al. 2014; Hughes and Palen 2012; Stephens, Robertson, et al. 2018), especially for filtering this big crisis data to extract relevant, serviceable calls for help (Castillo 2016; Purohit et al. 2018). Furthermore, the public believes official agencies are monitoring social media (American Red Cross 2011), but that is often not the case as most agencies lack the available resources to dedicate to performing this emerging function while simultaneously fulfilling their other responsibilities (Peterson 2015).

In this paper, we use past research on social media use in disasters combined with first-hand emergency response experiences, to develop a framework useful in identifying patterns for the social media posts when citizens issue calls for help. We identify the importance and need for incorporating practitioner experience, knowledge, and feedback into computational methods for information filtering. We also discuss how future research can validate our framework, initially using existing data from past hurricanes, and then extending into other forms of disasters where evacuations are needed. Our goal is to systematize this chaotic process to help emergency response officials make sense of near-real-time data and supplement boots-on-the-ground evacuation efforts.

The rest of the paper is organized as follows. We first describe prior work on social media use in disasters, especially regarding calls for help, and review existing frameworks for processing social media. We then propose our framework for identifying and studying evacuation-related calls for help.

SOCIAL MEDIA USE IN DISASTERS

In the past two decades, research on social media use in disasters has significantly grown (Palen and Hughes 2018; Reuter et al. 2018). With social media technologies (e.g., Twitter, Facebook, Reddit, Snapchat, and Nextdoor), and the prominent use of mobile devices, people have many options for receiving information and even participating in disaster-related conversations (Hughes et al. 2008; Murthy and Longwell 2013; Palen and Liu 2007). Citizens are no longer reliant on official emergency information sources to disseminate urgent information because individuals can function as citizen journalists (Sutton et al. 2008). Meanwhile, emergency response organizations are seeking ways to effectively use social media in their response efforts, which includes searching social media channels for information that could be helpful in the formal response as well as monitoring for misinformation and false rumors that need correction (Denef et al. 2013; Hughes and Palen 2012; Latonero and Shklovski 2011). This type of monitoring can be challenging though, because emergency response organizations often lack the resources (staff and tools), expertise, and managerial support to do the task well (Hughes and Palen 2012; Plotnick and Hiltz 2016). The research presented here hopes to at least partially address some of these challenges by making it easier for emergency responders to find calls for help in the deluge of social media following a disaster event.

Social Media Calls for Help

While we know a considerable amount of literature concerning general uses of social media during disasters (Palen and Anderson 2016), the 2017 Hurricane season experienced a rise in the number of times that average citizens posted messages on social media requesting evacuation and other types of help—a phenomenon we refer to as a *call for help*. This is not necessarily a new practice (Hughes et al. 2014), but the idea of a public call for help is receiving attention from federal agencies like the Department of Defense and FEMA, as well as being seen in the recent research funding from the agencies such as U.S. National Science Foundation. In this paper, we further advance the notion of a *consequential call for help*, defined as a social media post by citizens in a disaster zone resulting from official public safety communication channels such as 9-1-1 in the U.S. becoming overloaded or disrupted as a result of the disaster impact.

By examining social media content, we propose to better understand how citizens interact with the evacuation practices communicated by emergency response organizations. While researchers have shown that private social media can be helpful in understanding what hurricane and flooding-related consequential calls for help look like in terms of images and text (Smith et al. 2018; Stephens et al. 2018), it is important to better understand what can be accomplished using public data from social media platforms like Twitter. Determining meaningful patterns and drilling down to specific disaster-related content, can be challenging using public data (Imran et al. 2014a; Li et al. 2015; O'Neal et al. 2018; Purohit et al. 2014). But once researchers and organizations optimize existing analytical tools for mining such public social data, it will be essential to have a robust methodological framework to systematically improve decision making for response to calls for help.

Getting access to private social media data is difficult, and by using public data, emergency response officials can call upon non-emergency management personnel and citizens to digitally converge and help make sense of social media data. Even though these digital volunteers may have no formal role in the evacuation process or direct contact with emergency response officials, they represent a powerful force that can be ready to serve in times of crisis (Hughes and Tapia 2015; Purohit et al. 2016; Starbird and Palen 2011).

Existing Frameworks and Tools for Near-Real-Time Social Media Analysis

There has been extensive research on social media analytics in the past decade and consequently, several frameworks and tools exist in the literature (Imran et al. 2015; Li et al. 2017; Poblet et al. 2018).

A systematic framework is required to computationally process big social data streams during disasters. Therefore, recent advancements in the design of real-time social stream analytics systems for disaster informatics applications have shown much promise (e.g., CitizenHelper (Karuna et al. 2017), AIDR (Imran et al. 2014b), Twitris (Sheth et al. 2014), CrisisTracker (Rogstadius et al. 2013), Twitcident (Abel et al. 2012)). The primary foundation of these frameworks is the use of machine learning and data mining, which may sometimes be erroneous in descriptive, predictive, and prescriptive modeling due to the lack of generalization of methods across the types of disaster events, languages, and regions. A gap in the design of such frameworks—one that we seek to fill—is that they do not effectively leverage human knowledge. Such knowledge can provide the context for information processing and can be extremely advantageous for improving the efficiency of near-real-time social media analytics during evacuations. We propose the need for utilizing human-in-the-loop methods for machine learning and data mining approaches such as active learning with concept drifts and the hybrid systems of human-knowledge driven rule-based learners and the conventional data-driven learners. Such human knowledge-driven methods would improve the capturing and processing of rapidly changing nature of the concept of relevant information in the data stream as the disaster evolves.

DESIGNING A PRACTITIONER KNOWLEDGE-DRIVEN EVACUATION ANALYTICS FRAMEWORK

We begin this framework development by identifying distinguishing features of social media content from both citizens and emergency response organizations. This framework was designed with the assumption emergency response organizations are aware their region could be impacted by the pending hurricane and have the ability to collect and monitor hurricane-related social media data. We propose using the Twitter Search API to access information about evacuation-related tweets. We focus on one social media platform, Twitter, to keep our demonstration of the framework manageable. We hope to expand our framework to include other social media platforms in the future. Although images can be helpful in analytics, and research literature has begun to determine how these classifiers will work (Stephens, Li, et al. 2018), we focus solely on social media text to avoid scope-creep in our proposal. With a goal of using this framework in near-real-time situations, we outline a model consisting of six major stages: 1) ***planning***, 2) ***collecting*** data, 3) ***filtering***, 4) detecting ***location***, 5) ***re-filtering*** based on changing disaster dynamics, and 6) sorting data into degrees of ***relevance*** to assist with emergency response. We begin by describing activities that happen before the disaster strikes.

Planning

Planning is an integral part of any disaster preparation. There are two key considerations in our framework that must be accomplished during the planning stage: 1) determining meaningful times for data collection and analysis and 2) identifying keywords for filtering.

However, before activity can begin, if research is overseen by an institutional review board (IRB) as part of a data collection and analysis process, getting that oversight process in place before the disaster strikes is important. Several scholars from the National Institute of Environmental Health Sciences Working Group have created helpful documents to assist researcher/practitioner collaborations in working with their IRBs (Packenham et al. 2017). Having conversations concerning how every member of the team will benefit from the intense near-real-time effort is an important part of making these partnerships sustainable.

Determine Meaningful Times for Data Collection and Analysis

One helpful thing about a disaster that develops over time, as opposed to an immediate threat, is the time people have to make decisions and prepare (Tierney et al. 2001). However, with this time also comes changing conditions—disaster dynamics—and that means emergency responders need to both predetermine and contingency plan for a meaningful time period for near-real-time data collection. This preplanning is important for emergency response personnel who are monitoring social media data because the amount of data will continue, and possibly increase with changing conditions. There needs to be time-points where some members of the team stop monitoring social media and spend time analyzing what they are seeing. This represents a meaningful snapshot that can be fed into the monitoring process to create a dynamic system to identify calls for help.

Figure 1 provides an illustration of how some virtual teams are analyzing social media data and feeding findings back to emergency response personnel. The gray circle represents a time-point during the disaster when data collection ends and analysis begins. The black arrows represent subsets of data created from adjusting the relevancy level of the original dataset. The Emergency Operations Center and/or assigned liaison receive findings from the virtual team and decide whether the information is suitable for communicating to the physical team in the field. This reporting structure is the demarcation between virtual and physical teams and ensures normal operating procedures are not disrupted.

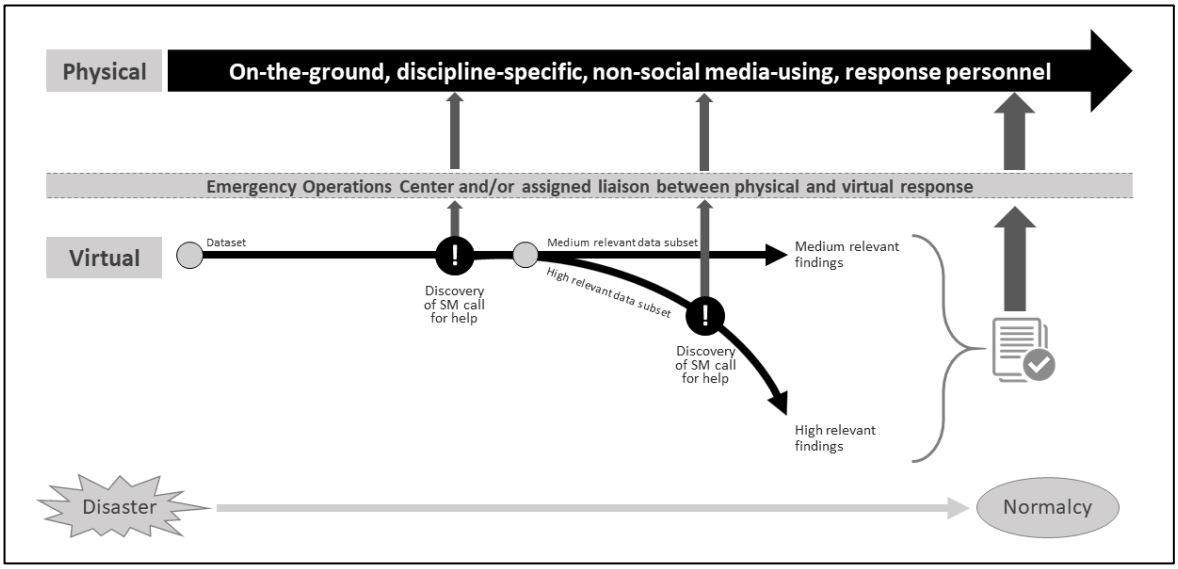


Figure 1: Example of How Social Media Findings Reach Emergency Responders through a Liaison

Identify Keywords

The second major task to accomplish before a disaster strikes is to determine keywords that have meaning for the respective emergency support function associated with the pending disaster. Table 1 illustrates examples extracted from a list of evacuation-related keyword/search terms our team generated by searching FEMA documentation, referencing past disasters that involved evacuations, and consulting emergency management officials. These keywords have been used to find relevant information in past events. Based on our research, these should form the starting point for a search for evacuation-related social media calls for help. Note that these keywords reflect a combination of transportation-related concepts, as well as descriptive terms helpful when searching public data for relevant indicators of calls for help.

Table 1. Keyword Sample Proposed for an Evacuation Analytics Framework

alternate	evacuate	junction	relocate
blocked	fuel	lane	route
closed	gas	mandatory	shelter
contraflow	highway	overflow	traffic
detour	interstate	parking lot	vehicle

We believe generating a large quantity of evacuation-related keywords, communicated either by emergency response organizations or by citizens or a combination of both, will hold a high possibility of discovering calls for help during hurricane evacuations. To strengthen results from this methodological framework, we recommend reviewing evacuation-related social media messages authored by emergency response organizations during past hurricanes to locate additional keywords.

Data Collection

After the planning stage, data collection begins. Sources for obtaining social media data during a disaster event include social media platform APIs (such as the Twitter Streaming API) or data aggregation tools. These sources are searched using high-level terms or hashtags (or location bounding boxes for the affected region) that capture a broad spectrum of data, which might be relevant to the event. For example, common terms for a hurricane include the name of the hurricane (e.g., Hurricane Harvey) and the locations affected by the event (e.g., Rockport, Fulton, Houston). As the event unfolds, these terms are often updated. The retrieved data contains a variety of metadata along with each social media message, including the message content, posting time, geolocation

coordinates if available, and the author profile information. The collected data is then stored in a database or a data file for later filtering and analysis.

Filtering

This step of the framework takes the data collected in the prior step and filters the data using the list of evacuation-related keywords that were determined in the planning stage. To filter the data, a computer program can be used to extract the social media messages containing the keywords. This step produces a subset of data that is more manageable and more likely to be related to an evacuation. A hurricane event usually produces far more information than can be examined manually. Therefore, the filtering step is important for narrowing down evacuation-related information, including calls for help, required to be examined more closely.

Location Detection

The next step in our framework is to associate a location with each message (when possible). Having a precise location for a call for help is essential provided the goal is to physically rescue the individual(s) or to provide evacuation-related information relevant to their location. But obtaining location information can be challenging when using public social media. A direct way to get location data is through geolocation metadata automatically embedded in the tweet data, however, geolocation data is not required and most messages do not contain it. Location can also be inferred from user profile data, social connections, or the content of the message (Stock 2018). Sometimes location data is manually entered by the social media end user. For example, during the 2017 hurricane season, some people posted their own address publicly, or a friend or family member did this for them (Stephens, Robertson, et al. 2018). For example, messages like this occurred:

> *My mother needs help. 3390 ISCRAM Lane. 2 older adults, 1 dog.*

There could be considerable privacy issues with this practice, but it appears that some people do not consider that a barrier when they feel their life is in jeopardy. Two challenges are associated with this process of manually sharing location data: redundancy and closing the loop (Smith et al. 2018). It is quite possible for multiple people to post the same location data either without or with full knowledge that these are redundant posts. Another challenge found in coordinating these types of rescues is that once someone was rescued, there is no easy way to close the loop (Smith et al. 2018). This challenge provides further evidence of the importance of emergency response organizations, or the dedicated resources assisting them, to centralize findings and communicate to responders in the field. Responders in the field are emergency response organizations' ground truth – confirming or delegitimizing social media calls for help. Therefore, in the process of including location data into the decision-making process, people monitoring social media should pay careful attention to redundancy, and look for alternative verifying information suggesting that people have been rescued.

Re-Filtering

In this step, we re-evaluate the way the data has been analyzed and filtered up to this point, incorporating insights based on changing disaster dynamics and the results of the location detection step. Figure 1 shows how it is not uncommon to have multiple teams analyzing social media, and this re-filtering step is a place in the framework where these teams can inform and shape the social media strategy for all teams. Re-filtering allows different views on the collected data for creating the task-specific filtered sets for different functions of the response stakeholder teams. This is also an opportunity to incorporate practitioner expertise into the filtering and analysis. Unlike most other analytics frameworks for social media in disaster, this framework seeks to leverage human knowledge (especially that of practitioners) and the re-filtering step is an important place where this can happen.

Message Relevancy

When combining the filtering process with location detection, the next step in our evacuation analytics framework invites people monitoring social media to assign relevancy criteria to each piece of data. Once again, the goal is to simplify the decision making during the chaos of a disaster, so we propose using a simple four-number Likert Scale rating system to help rate the quality of the calls for help data as done in the prior work (e.g., rating the serviceability characteristics of social media requests (Purohit et al., 2018)). The highest quality call for help is assigned a 3 and contains both evacuation-related key words and location information. Next, if the location information is missing, but the key words still indicate the tweet is evacuation related, it is assigned a 2. If there

is no location information and the key words are not clearly related to an evacuation need, it is assigned a 1. Finally, for all data that does not seem related to an evacuation, it is assigned a 0. Table 2 explains this rating system succinctly. The results of this step can then be aggregated and reported to the relevant emergency response organization.

Table 2: Criteria for Rating Filtered Twitter Data

Rating	Relevancy	Criteria
3	[HIGH] More accurate	Evacuation-related and location identified
2	[MEDIUM] Moderately accurate	Evacuation-related
1	[LOW] Less accurate	Evacuation-related uncertainty
0	No relevancy	No correlation to evacuation

The Framework

Our proposed framework (described above) identifies and isolates actionable intelligence associated with evacuations. This framework could become a pre-emptive strategy for implementation in future advance notice disasters, such as hurricanes, by practitioners. Figure 2 provides an overview of the steps in our evacuation analytics framework.

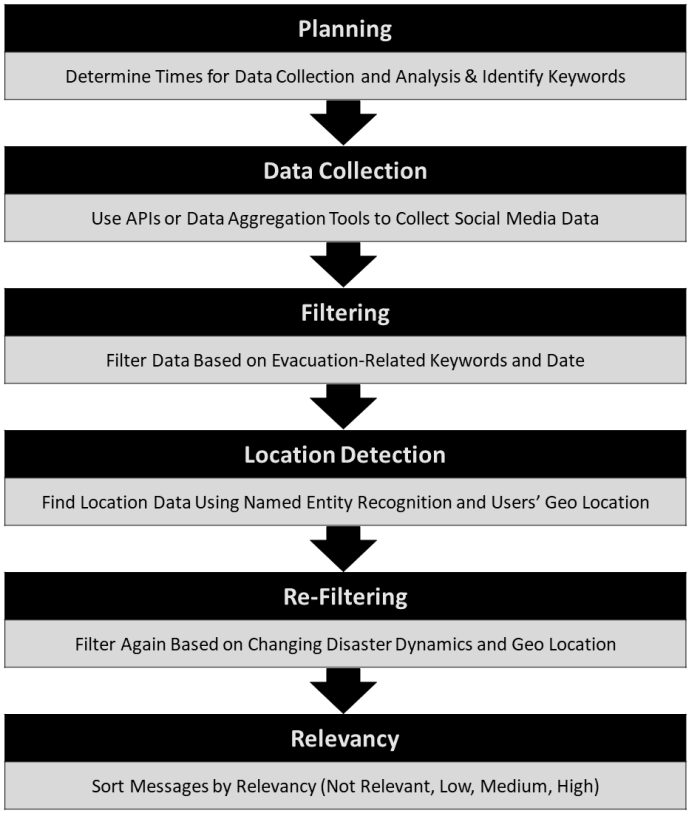


Figure 2: Framework for Extracting Evacuation-Related Social Media Content

VALIDATING THE PROPOSED FRAMEWORK

For validating the framework developed here, we propose using an approach similar to one used by Banujan, Banage, and Paik (2018). To ensure we have captured the most crucial, indispensable keywords that would be advantageous in extracting meaningful data from Twitter, we plan to compare three different social media disaster datasets related to hurricane evacuation. Also, we will perform a comparative analysis between the filtered results by consolidating all three dataset findings. This should surface data that identifies and describes common themes that will shed light on human behavior during hurricane crises. These findings may also aid emergency response organizations to take pre-emptive communication measures in future disasters, during the pre-crisis phase, to

disseminate time-sensitive emergency messaging.

However, the question remaining is whether citizen reports on social media during evacuation periods can be gathered, consolidated, analyzed, categorized, and verified for accuracy in time to be helpful during the same evacuation period. Conducting a comparative study as suggested in this paper should aid in answering this question. Specifically, applying the integrative methodology to the datasets should confirm whether or not this is plausible.

DISCUSSION

In this research, we propose a systematic framework that can be used to streamline a near-real-time public social media strategy to identify calls for help. Our review of the literature combined with the knowledge of emergency responders identified the importance of integrating social media planning—i.e., key word identification—into the disaster preplanning processes. Furthermore, by establishing multiple teams of social media monitors and analysts, these groups can more quickly identify calls for help, determine location data, rate the overall data, and share the prioritized data with responders in the field. This framework may seem overly simplistic. However, considering that social media has often been the afterthought of an emergency response, this practitioner knowledge-driven analytics framework can help systematize the inclusion of this important publicly communicated data within emergency response organizations' efforts in responding to a disaster.

Future Directions & Conclusion

The next step for this research, and one in which we are currently engaged, is to validate our framework using multiple hurricane data sets. Once this step is complete, we can see if with different keywords, the framework could be successfully applied to other disaster types. It will be important to ascertain if the framework can be applied to both advance-notice and no-notice disasters. It is also prudent that non-evacuation related social media calls for help are also captured, categorized, and studied to influence future mitigation efforts in the respective emergency support function areas.

We hope findings from studying multiple datasets—the keywords, differences, and similarities—will better position practitioners in future hurricane situations, as well as in other types of disasters. Testing and implementing this proposed framework for discovering actionable social media data pertaining to disasters could aid agency policy makers in adopting and promoting more integrative approaches to rescuing people. Results may also provide practitioners, especially those advocating to include social media, further evidence concerning how to retrieve, validate, and understand near-real-time social media data. This could assist in decision making as well as strengthen confidence in social media. It will take considerable research efforts, but these results may be the catalyst for addressing this need (Peterson et al. 2018). Finally, results may shed new light on this underexplored, critical area of the response phase of emergency management. These efforts have the potential to further enhance the value of preparing, responding, and recovering from emergencies by embedding social media within various constructs/organizational structures.

REFERENCES

Abel, F., Hauff, G.-J., Houben, K. T., and Stronkman, R. (2012). "Semantics + Filtering + Search = Twitcident Exploring Information in Social Web Streams." *Proceedings of the 23rd ACM Conference on Hypertext and Social Media*, ACM Press, New York, NY, 285–294.

American Red Cross. (2011). *Social Media in Disasters and Emergencies*.

Banujan, K., Kumara, T. G. S. B., and Paik, I. (2018). "Twitter and Online News analytics for Enhancing Post-Natural Disaster Management Activities." *2018 9th International Conference on Awareness Science and Technology (iCAST)*, 302–307.

Castillo, C. (2016). *Big Crisis Data: Social Media in Disasters and Time-Critical Situations*. Cambridge University Press, New York, NY, USA.

Denef, S., Bayerl, P. S., and Kaptein, N. (2013). "Social Media and the Police-Tweeting Practices of British Police Forces during the August 2011 Riots." *Proceedings of the 2013 Conference on Human Factors in Computing Systems (CHI 2013)*, ACM Press, New York, NY, 3471–3480.

Dynes, R. R. (1970). *Organized Behavior in Disaster*. D.C. Heath, Lexington, Massachusetts.

Federal Communications Commission. (2018). *2017 Atlantic Hurricane Season Impact on Communications: Report and Recommendations*.

Hiltz, S. R., Kushma, J. A., and Plotnick, L. (2014). "Use of Social Media by U.S. Public Sector Emergency Managers: Barriers and Wish Lists." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2014)*, University Park, PA.

Hughes, A. L., and Palen, L. (2012). "The Evolving Role of the Public Information Officer: An Examination of Social Media in Emergency Management." *Journal of Homeland Security and Emergency Management*, 9(1).

Hughes, A. L., Palen, L., Sutton, J., Liu, S. B., and Vieweg, S. (2008). "'Site-Seeing' in Disaster: An Examination of On-Line Social Convergence." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2008)*, Washington D.C.

Hughes, A. L., St. Denis, L. A., Palen, L., and Anderson, K. M. (2014). "Online Public Communications by Police & Fire Services during the 2012 Hurricane Sandy." *Proceedings of the 2014 International Conference on Human Factors in Computing Systems (CHI 2014)*, ACM Press, New York, NY, 1505–1514.

Hughes, A. L., and Tapia, A. H. (2015). "Social Media in Crisis: When Professional Responders Meet Digital Volunteers." *Journal of Homeland Security and Emergency Management*, 12(3), 679–706.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015). "Processing Social Media Messages in Mass Emergency: A Survey." *ACM Comput. Surv.*, 47(4), 67:1–67:38.

Imran, M., Castillo, C., Lucas, J., Meier, P., and Rogstadius, J. (2014a). "Coordinating Human and Machine Intelligence to Classify Microblog Communications in Crises." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2014)*, University Park, PA.

Imran, M., Castillo, C., Lucas, J., Meier, P., and Vieweg, S. (2014b). "AIDR: Artificial Intelligence for Disaster Response." *Proceedings of the Companion Publication of the 23rd International Conference on World Wide Web Companion*, WWW Companion '14, International World Wide Web Conferences Steering Committee, Republic and Canton of Geneva, Switzerland, 159–162.

Karuna, P., Rana, M., and Purohit, H. (2017). "CitizenHelper: A Streaming Analytics System to Mine Citizen and Web Data for Humanitarian Organizations." *Proceedings of the Eleventh International Conference on Web and Social Media*, Montréal, Québec, Canada, 729–730.

Latonero, M., and Shklovski, I. (2011). "Emergency Management, Twitter, and Social Media Evangelism." *International Journal of Information Systems for Crisis Response and Management*, 3(4), 1–16.

Li, H., Guevara, N., Herndon, N., Caragea, D., Neppalli, K., Caragea, C., Squicciarini, A., and Tapia, A. H. (2015). "Twitter Mining for Disaster Response: A Domain Adaptation Approach." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2015)*, Kristiansand, Norway.

Li, T., Xie, N., Zeng, C., Zhou, W., Zheng, L., Jiang, Y., Yang, Y., Ha, H.-Y., Xue, W., and Huang, Y. (2017). "Data-Driven Techniques in Disaster Information Management." *ACM Computing Surveys (CSUR)*, 50(1), 1.

Murthy, D., and Longwell, S. A. (2013). "Twitter and Disasters: The Uses of Twitter during the 2010 Pakistan Floods." *Information, Communication & Society*, 16(6), 837–855.

O'Neal, A., Rodgers, B., Segler, J., Murthy, D., Lakuduva, N., Johnson, M., and Stephens, K. K. (2018). "Training an Emergency-Response Image Classifier on Signal Data." *Machine learning and applications*.

Packenham, J. P., Rosselli, R. T., Ramsey, S. K., Taylor, H. A., Fothergill, A., Slutsman, J., and Miller, A. (2017). "Conducting Science in Disasters: Recommendations from the NIEHS Working Group for Special IRB Considerations in the Review of Disaster Related Research." *Environmental Health Perspectives*, 125(9).

Palen, L., and Anderson, K. M. (2016). "Crisis Informatics—New Data for Extraordinary Times." *Science*, 353(6296), 224–225.

Palen, L., and Hughes, A. L. (2018). "Social Media in Disaster Communication." *Handbook of Disaster Research*, Handbooks of Sociology and Social Research, H. Rodriguez, W. Donner, and J. E. Trainor, eds., Springer International Publishing, 497–518.

Palen, L., and Liu, S. B. (2007). "Citizen Communications in Crisis: Anticipating a Future of ICT-supported Public Participation." *Proceedings of the 2007 Conference on Human Factors in Computing Systems (CHI 2007)*, ACM Press, New York, NY, 727–736.

Peterson, S. (2015). "Socia Media Resources for Emergency Management." *International Association of Emergency Managers Bulletin*, 36(6), 34–36.

Peterson, S., Thompson, C., and Graham, C. (2018). "Getting Disaster Data Right: A Call for Real-Time Research in Disaster Response." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2018)*, Rochester, NY.

Plotnick, L., and Hiltz, S. R. (2016). "Barriers to Use of Social Media by Emergency Managers." *Journal of Homeland Security and Emergency Management*, 13(2), 247–277.

Poblet, M., García-Cuesta, E., and Casanovas, P. (2018). "Crowdsourcing Roles, Methods and Tools for Data-Intensive Disaster Management." *Information Systems Frontiers*, 20(6), 1363–1379.

Purohit, H., Castillo, C., Imran, M., and Pandev, R. (2018). "Social-eoc: Serviceability Model to Rank Social Media Requests for Emergency Operation Centers." *2018 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM)*, IEEE, 119–126.

Purohit, H., Dalal, M., Singh, P., Nissima, B., Moorthy, V., Vemuri, A., Krishnan, V., Khursheed, R.,

Balachandran, S., Kushwah, H., and Rajgaria, A. (2016). "Empowering Crisis Response-Led Citizen Communities: Lessons Learned from JKFloodRelief.org Initiative." *Strategic Management and Leadership for Systems Development in Virtual Spaces*, 270–292.

Purohit, H., Hampton, A., Bhatt, S., Shalin, V. L., Sheth, A. P., and Flach, J. M. (2014). "Identifying Seekers and Suppliers in Social Media Communities to Support Crisis Coordination." *Computer Supported Cooperative Work (CSCW)*, 23(4–6), 513–545.

Reuter, C., Hughes, A. L., and Kaufhold, M.-A. (2018). "Social Media in Crisis Management: An Evaluation and Analysis of Crisis Informatics Research." *International Journal of Human–Computer Interaction*, 34(4), 280–294.

Rhodan, M. (2017). "Hurricane Harvey: The U.S.'s First Social Media Storm." *Time*.

Rogstadius, J., Vukovic, M., Teixeira, C. A., Kostakos, V., Karapanos, E., and Laredo, J. A. (2013). "CrisisTracker: Crowdsourced Social Media Curation for Disaster Awareness." *IBM Journal of Research and Development*, 57(5), 4:1-4:13.

Sheth, A., Jadhav, A., Kapanipathi, P., Lu, C., Purohit, H., Smith, G. A., and Wang, W. (2014). "Twitris: A System for Collective Social Intelligence." *Encyclopedia of Social Network Analysis and Mining*, R. Alhajj and J. Rokne, eds., Springer New York, New York, NY, 2240–2253.

Smith, W. R., Stephens, K. K., Robertson, B. W., Li, J., and Murthy, D. (2018). "Social Media in Citizen-Led Disaster Response: Rescuer Roles, Coordination Challenges, and Untapped Potential." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2018)*, Rochester, NY.

Starbird, K., and Palen, L. (2010). "Pass It On?: Retweeting in Mass Emergency." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2010)*, Seattle, WA.

Starbird, K., and Palen, L. (2011). "'Voluntweeters:' Self-Organizing by Digital Volunteers in Times of Crisis." *Proceedings of the 2011 Conference on Human Factors in Computing Systems (CHI 2011)*, ACM Press, New York, NY, 1071–1080.

Stephens, K. K., Li, J., Robertson, B. W., Smith, W. R., and Murthy, D. (2018). "Citizens Communicating Health Information: Urging Others in Their Community to Seek Help During a Flood." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2018)*, Rochester, NY.

Stephens, K. K., Robertson, B. W., and Murthy, D. (2018). "Throw Me a Lifeline!: The Affordances of Social Media and Mobile Phones during Rescues from Huricane Harvey." *Paper Presented at the National Communication Association Conference*, Salt Lake City, UT.

Stock, K. (2018). "Mining Location from Social Media: A Systematic Review." *Computers, Environment and Urban Systems*, 71, 209–240.

Sutton, J. N., Palen, L., and Shklovski, I. (2008). "Backchannels on the Front Lines: Emergent Use of Social Media in the 2007 Southern California Fires." *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2008)*, Washington D.C.

Tierney, K. J., Lindell, M. K., and Perry, R. W. (2001). *Facing the Unexpected: Disaster Preparedness and Response in the United States*. John Henry Press, Washington D.C.

Wachtendorf, T., Kendra, J. M., and DeYoung, S. E. (2018). "Community Innovation and Disasters." *Handbook of Disaster Research*, Handbooks of Sociology and Social Research, H. Rodríguez, W. Donner, and J. E. Trainor, eds., Springer International Publishing, 387–410.

Enhancing the usability of a disaster app: exploring the perspectives of the public as users

Marion Lara Tan
Massey University
m.l.tan@massey.ac.nz

Raj Prasanna
Massey University
r.prasanna@massey.ac.nz

Kristin Stock
Massey University
k.stock@massey.ac.nz

Emma Hudson-Doyle
Massey University
e.e.hudson-doyle@massey.ac.nz

Graham Leonard
GNS Science
g.leonard@gns.cri.nz

David Johnston
Massey University
d.m.johnston@massey.ac.nz

ABSTRACT

Limited research has studied how citizens' perspectives as end-users can contribute to improving the usability of disaster apps. This study addresses this gap by exploring end-user insights with the use of a conceptual disaster app in the New Zealand (NZ) context. NZ has multiple public alerting authorities that have various technological options in delivering information to the population's mobile devices; including social media platforms, apps, as well as the Emergency Mobile Alert system. However, during critical events, the multiplicity of information may become overwhelming. A disaster app, conceptualised in the NZ context, aims to aggregate, organise, and deliver information from official sources to the public. After the initial conceptual design, a usability inquiry was administered by interviewing members of the public. Partial results of the inquiry show that the public's perspective has value; in the process of understanding the new user's viewpoint, usability highlights and issues are identified.

Keywords

Usability inquiry, mobile application, disaster, alerts, public perspective

INTRODUCTION

Multiple apps exist to prepare and warn the public for disaster events. These include built-for-purpose disaster apps as well as social media platforms used by authorised agencies. Alerts and warnings can come from multiple sources through various platforms (Wright et al. 2014). However, during critical events, the multiplicity of information may become overwhelming for the user. Information overload can occur when human capacity can no longer process the torrent of data arriving (Stratmann and Boll 2016). To circumvent such difficulties, efforts have been made to create apps that curate emergency information needs. Disaster apps have been developed to have the capability to collate and disseminate information (Bachmann et al. 2015; Tan et al. 2017).

Disaster apps have the potential for improving the public's preparedness and response, but these technologies also pose risks if they are not appropriately designed in the context of its users (Tan et al. 2017). However, only a few studies on disaster apps have addressed the usability of the apps' interfaces (Romano et al. 2016; Tan et al. 2017).

The literature on the usability of technologies for disaster situations usually focus on responders as intended users and not the general public; for example, studies with police (e.g. Kuula et al. 2013) and firefighters (e.g. Prasanna et al. 2013). Only a few studies evaluate disaster technology applications from the perspective of civilians as the targeted users (Tan et al. 2017). Furthermore, most usability studies on mobile apps look into products used in casual environments and not in disaster contexts. For example, on social media apps (e.g. Hoehle et al. 2015), mobile banking apps (e.g. Mohan et al. 2015), and health apps (e.g. Schnall et al. 2016).

Considering these gaps, this research project seeks to explore how the insights of the citizens as users provide valuable perspectives in understanding and enhancing the usability of a disaster app. The research project employs usability inquiry, using interviews with eighteen participants, to investigate the users' perspective on a New Zealand (NZ) based conceptual disaster app.

The paper is structured as follows. The paper starts with a brief background on past studies of usability and disaster apps. Then we introduce the context and rationale behind our NZ based conceptual app. The methodology for the usability inquiry follows. Initial and partial results of the study are then presented. Finally, the paper concludes with the next steps for the research.

DISASTER APP USABILITY

It is important that users can effectively interact with apps; more so during crises, the apps should be usable even when users are under stress (Sarshar et al. 2015). Disaster apps must address the usability challenges of mobile interfaces and also consider the usability issues for safety-critical systems.

Mobile interfaces have their own set of usability challenges; specific issues, among others, include small screen size and the mobility of users (Gomez et al. 2014; Zhang and Adipat 2005). Using mobile apps may require more cognitive load from users; hence, mobile app usability models must consider new dimensions to account for the mobile app context (Harrison et al. 2013). Hoehle and Venkatesh (2015) conducted a prominent study on mobile app usability; they argued extensively for a differentiated mobile app usability model that diverges from software and website models. Analysing past literature on mobile app usability, as well as industry guidelines, Hoehle and Venkatesh (2015) proposed a mobile app usability model that comprised of six factors: app design, app utility, user interface (UI) graphics, UI output, UI input, and UI structure. However, literature that extended from this study has only been implemented on social media apps (e.g. Hoehle et al. 2015).

The lack of usability of crisis-related technological products can lead to compromised safety of its users (Nurse et al. 2012). Individuals can act differently when under pressure (Hiltz et al. 2010). In a review of safety-critical systems literature, supporting the human experience is essential to usability. Five recommendations are highlighted for disaster-related technologies: minimise user memory workload, use simple graphics and structure, avoid information overload, provide contextualised and updated information, and maintain a degree of automation but still keeps the user in the loop (Kwee-Meier et al. 2017). Understanding users and their decision making qualities in stressful conditions are essential when designing technologies for disaster management (Hiltz et al. 2010). User studies are valuable in guiding the design of safety-critical systems (Kwee-Meier et al. 2017).

Usability studies on disaster apps

As it applies to mobile apps and technologies for safety-critical systems, disaster apps should carefully consider usability. A recent study by Tan et al. (2018) tested and re-developed the Hoehle and Venkatesh (2015) model. Using survey responses from 270 actual disaster app users, Tan et al. (2018) proposed a usability-continuance model that fits the disaster app context; five factors were found to affect users' perception on whether to continue or abandon disaster apps: (1) app utility, (2) app dependability, (3) UI output, (4) UI input, and (5) UI graphics.

Before Tan et al.'s (2018) study, only a few papers had evaluated the usability of apps that are built specially for disaster purposes. Sarshar et al. (2015) investigated the usability of two disaster apps, GDACSmobile and SmartRescue; their study highlighted the importance of considering human-computer interaction (HCI) in the design of disaster apps. Furthermore, Sarshar et al. (2015) suggested that to have a deeper understanding of the usability of disaster apps, future research should investigate various usability testing methods.

Moreover, other studies on disaster apps focus on apps' functionalities and only briefly mentions engaging the users to assess usability (Tan et al. 2017). Often, user testing is employed either as a means to prove functional effectiveness or as a step to improve the app's functionality (e.g. Kaufhold et al. 2018; Kolathayar et al. 2018). However, Estuar et al. (2014) argued that engaging users should not just be for assessing functionality; understanding the user experience can help make an app's interface relevant to intended users. Reuter et al. (2017) encouraged the use of participatory methods with users to capture their perspective in the app design.

CONCEPTUALISATION OF A DISASTER APP IN NEW ZEALAND

This paper showcases how gathering user feedback through a usability inquiry can provide valuable insights in enhancing the usability of a disaster app. To begin, we introduce the app under study. This section discusses the rationale behind the conceptualisation of a disaster app in NZ. The disaster app concept is to aggregate the information available from authorised agencies about a crisis or a disaster and deliver it to the public through a simple platform.

In NZ, multiple agencies have the mandate to warn the public on actual or suspected threats, risks, hazards or emergencies (Ministry of Civil Defence and Emergency Management 2017). The Ministry of Civil Defence and Emergency Management (MCDEM) operates the National Warning System, which is the primary channel to communicate national level warnings to local Civil Defence and Emergency Management (CDEM) agencies. The members of sixteen regional CDEM Groups have the responsibility to provide official alerts, including calls to action, to their communities for hazards. Also, monitoring agencies such as GNS Science (geological survey) and the MetService (meteorological agency) also provide public alerting related to their respective hazards (Wright et al. 2014). Moreover, the NZ Police, Fire and Emergency NZ, NZ Transport Agency, Ministry of Health, and Ministry of Primary Industries also provide alerts related to their respective jurisdictions (Ministry of Civil Defence and Emergency Management 2017).

NZ CDEM collectively uses a multi-channel public-alerting approach, to ensure that many people can receive information, with redundancy. There are at least twenty public alerting platforms for these agencies to communicate to the public; these include billboards, radio announcement, cell broadcast, emails, loudspeakers, websites, etc. (Ministry of Civil Defence and Emergency Management, 2018). Multiple technological options exist to deliver alerts to the public through their mobile devices; these include apps, SMS-text message, phone calls, the use of social media platforms, and broadcast messaging (Wright et al., 2014).

Use of social media and apps in public alerting in New Zealand

Many of the NZ public alerting agencies use social media platforms to communicate (Wright et al. 2014). The public can access social media information through websites as well as through respective apps in their mobile devices. Through social media, the agencies communicate not only alerting messages but can also include everyday content such as preparedness advice (Wright et al. 2014).

However, in NZ the use of social media platforms have limitations. Users have to opt-in through individually following various accounts and have to check different streams and sources to receive updates (Wright et al. 2014). The presence of the agencies on popular social media platforms are not consistent. For example, not all NZ public alerting agencies have Facebook or Twitter accounts (Wright et al. 2014). A review of twenty-four alerting authorities on Facebook and Twitter shows that although most have official accounts on both social media platforms, some may have only one or the other, or none at all (Table 1 shows a cross tabulation). Another limitation of social media platforms is the reliance on third-party social media algorithms for providing information (Wright et al. 2014). Social media content does not necessarily come in chronological order (Biersdorfer 2016). Facebook prioritises posts from families and friends rather than organisations (Bromwich and Haag 2018).

Table 1. NZ public alerting agencies' social media presence as of 2018

		Facebook		Total
		Yes	No	
Twitter	Yes	18	2	20
	No	3	1	4
Total		21	3	24

When it comes to the use of mobile apps, three mobile apps are currently available in NZ that are affiliated with public alerting agencies. The GeoNet app is part of the geological hazard monitoring system in NZ; it is an app that allows the public to receive notifications for earthquakes and bulletins on volcanic activity (GeoNet n.d.). The MetService app provides information on weather conditions and forecasts as well as deliver severe weather warnings and watches (MetService n.d.). The Hazard app, developed and distributed by the NZ Red Cross, is a multi-hazard app endorsed and used by multiple CDEM groups (New Zealand Red Cross 2015).

Similar to the limitation of social media channels, mobile apps are opt-in platforms (Wright et al. 2014). Individuals have to consciously choose to download different apps to receive varying details of information on particular hazards that interests them.

With rapid changes in technology and the new media ecosystem, over-alerting can create issues in how the public responds to alerts (National Academies of Sciences Engineering and Medicine 2018a). During a crisis, users can encounter difficulties in making sense of too much data; information overload can occur when human capacity cannot keep up with the torrent of data arriving (Prasanna et al. 2013; Stratmann and Boll 2016). Aside from social media and other technological platforms, public alerting authorities can also push high-priority alerts via the Emergency Mobile Alert (EMA) system.

Emergency mobile alert in New Zealand

NZ had recently adopted the EMA system in 2017; which allows authorised agencies to release alerts via cell broadcast technology (Ministry of Civil Defence and Emergency Management 2017). Other countries have similar systems; for example, the Wireless Emergency Alert (WEA) in the United States of America (Bean et al. 2016), NL-Alert in the Netherlands (Gutteling et al. 2017), and Cell Broadcast Service (CBS) of Taiwan (Chang and Chen 2018).

The emergency alerts, different from text messages, do not cause network congestion as they are distributed through a geo-targeted wireless channel (Bean et al. 2016; Chang and Chen 2018). Moreover, the alert messages delivered to mobile phones are distinct from standard messages; they are uniquely displayed on devices accompanied by distinct tones and vibrations (Bean et al. 2016).

How an individual receives the message can affect how the individual responds to the threat (National Academies of Sciences Engineering and Medicine 2018b). During a crisis, users can encounter issues; anxiety, fatigue, and other stressors can hamper information processing (Stratmann and Boll 2016). The way information is processed, stored, and displayed can affect users (Prasanna et al. 2013). Technology for disasters must be efficiently designed to support the intake of information in stressful conditions.

Multiple studies have looked into the effectiveness of emergency alert messages; including studies on the technical capabilities (e.g. Chang and Chen 2018), on message content and style (e.g. Potter 2018), on citizens' response to messages (Gutteling et al. 2017). However, an understudied area is on how users interact with the alert message. The typical emergency alert message (see Figure 1) is delivered through a pop-up notification mechanism in the users' smartphone (Falcão et al. 2018). The simple message dialogue may be suitable to convey a single message during an unchanging situation, but multiple messages over a complex scenario may require a different manner of presentation to help the users' understand the situation (Iannucci et al. 2016).

Figure 1. Emergency alert example (Theunissen 2017)

Another interface issue, as encountered in the 2017 test broadcast in NZ, is the disappearance of the alert message when users tap on to the notification on their smartphones (Ministry of Civil Defence and Emergency Management n.d.). Although not identified in academic literature, smartphone users have anecdotally raised interface and retrieval issues for emergency alerts. Table 2 lists some of these anecdotes from users on online forums.

Table 2. Anecdotes on disappearing alert messages

Anecdotes	Forum
Last night I got an emergency alert. I didn't have my glasses on and as I reached for the phone, I lost the message. How can I find that message? Thanks. (2014)	Apple Discussions
I imagine most people push OK in a panic to stop the loud sound, and then are left wondering what it was exactly that was so important. (2014)	Android Stack Exchange
Where are emergency alerts (WEA) stored on the iPhone? One popped up and disappeared before I could read it. (2013)	Apple Discussions

Further research is needed to make the interface more intuitive. As technologies change, so do user behaviour and public response; continued research on human interaction with alert messages is critical (National Academies of Sciences Engineering and Medicine 2018a).

App conceptual design

The app used in this study, currently named 'NZ Alerts', aims to address the issues above. The app aggregates information from official sources and authorised alerting agencies into one platform; providing means to find critical information segregated from the noise of multiple media sources and other non-hazard related information. The app will collect, store, and display information that is made public by authorised agencies; these include preparedness information, social media messages, and EMA broadcasts.

The initial expectations for the app are (1) to lessen information overload by consolidating messages from various official social media sources and (2) to address the emergency alert interface issues by collating, storing, and displaying emergency alert messages for users. Also, the app provides preparedness information from reliable sources. The app's main features are partitioned into three screens (See Figure 2): home screen, prepare screen, and alert screen.

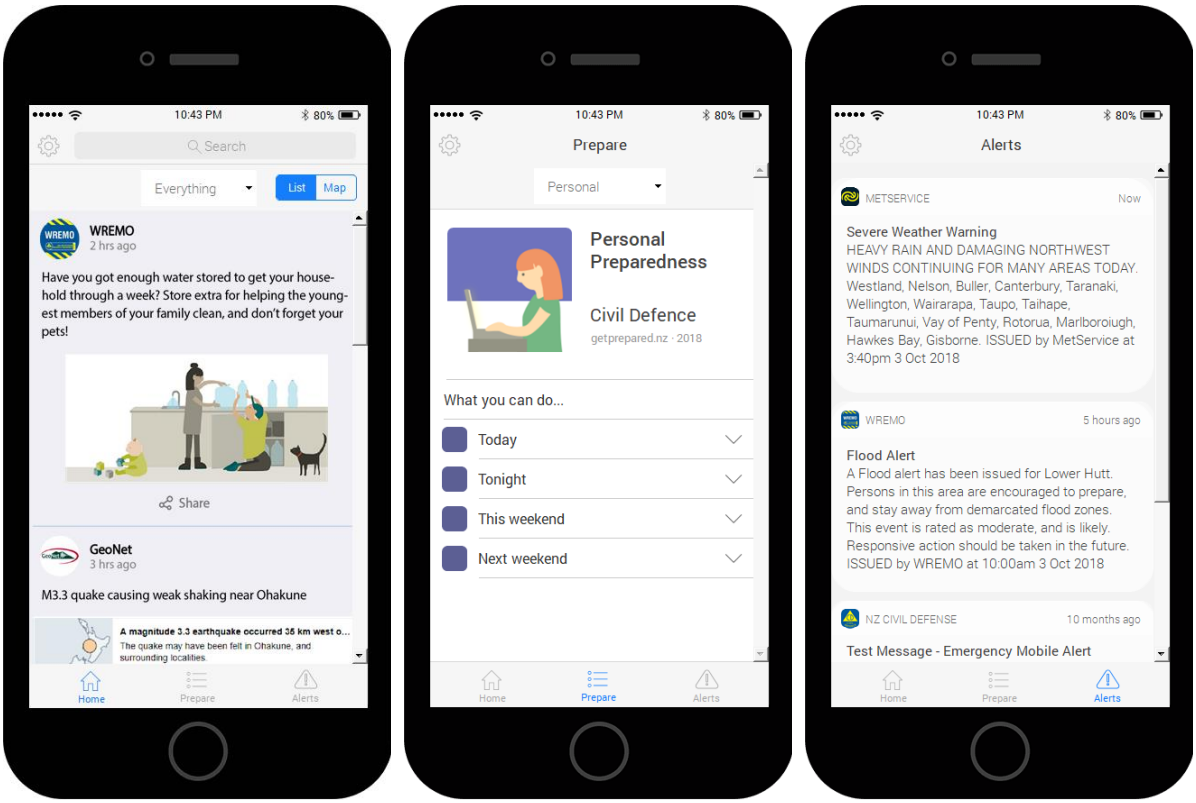


Figure 2. Screenshots of NZ Alerts app

Home screen

The home screen displays a real-time feed, harvesting content from participating authorities' social media channels. By collating information from official sources, it reduces the noise that may be encountered when using social media apps. In social media sites, posts on a users' feed can contain mundane topics that may become noise when seeking information about hazard events; separation of credible and reliable information from trivial ones is needed (Imran et al. 2015).

Prepare screen

Most of the apps in crisis informatics literature focus on the response and recovery stages (Tan et al. 2017). However, there is potential in utilising new media tools to encourage preparedness for a crisis (Veil et al. 2011). In addition to delivering up-to-date information from official agencies, the app will provide credible preparedness information. The prepare screen will be an offline repository of emergency preparedness information which users can access at any time.

Alert screen

The way information is processed, stored, and displayed can affect users' decision-making capabilities during critical scenarios (Prasanna et al. 2013). Users can make errors when under stress which may cause them to dismiss alerts before reading the information. The alert screen will collate, store, and display official emergency alert messages from authorities; allowing users to retrieve the information as needed.

With the combination of the above described three screens, the NZ Alerts app is expected to be a 'one-stop-shop' that aims to provide preparedness and response information on hazard events to the public living in NZ. It is essential that this initial app concept will be aligned with the expectation of the end-users when developed further to form a fully-fledged mobile app. Users can offer perspectives that can diverge or converge from the intended design; providing value in the design practices for disaster technologies (Petersen et al. 2015). The next section discusses the methods employed in this study to gain the users' perspective.

METHODS

The human-centred design is an important aspect in the field of disaster management (Fischer and Klompmaker 2012). As part of the user-centred approach taken in this study, inputs from potential users were gathered to obtain their perspective on the NZ Alerts app. A usability inquiry was conducted with the aim of recognising the new users' needs and understanding of the app. Inquiry methods directly involve talking to end-users; techniques include surveys, focus groups, or interviews (Folmer and Bosch 2004; Zapata et al. 2015). For this study, we conducted semi-structured interviews with eighteen participants. Before the recruitment and data collection, the usability inquiry went through an ethical approval process for human participation.

Participant recruitment

The target user for the app is an iPhone user living in NZ, aged eighteen or older; with or without previous experience in using a disaster app. The recruitment strategy was applied in two stages. First, we recruited participants from an earlier disaster app survey. The survey, of which had 562 participants, contained a follow-up question that asked whether the respondents would be willing to be interviewed for a usability study. We invited the willing respondents (n=89) to participate in the usability inquiry; of which nine people volunteered to be interviewed. We then recruited more participants by posting flyers in two university campuses. Another nine individuals participated until the interview data collection reached a saturation point.

Data collection

We first conducted two pilot interviews to refine the questions and the interview flow. All the interviews were conducted in-person only in Wellington, NZ; due to researchers' limitations. The interviews were semi-structured and had three parts (See Table 3). The interviews involved users interacting through each screen of the mock-up interface, and then the interviewer asked core questions and supplementary questions on each part. After interacting through the entire app, the participants were also asked core questions about the overall app in the particular context of a crisis scenario. Each interview took between 40 to 90 minutes.

Table 3. Interview guide core questions

Interview core questions
1. Demographic and participant information
2. Core questions for each screen (after user interacts freely with each screen)
a. Do you like the look? What comments or issues do you have?
b. Do you like the controls? What comments or issues do you have?
c. Is it intuitive to navigate around the screen? What comments or issues do you have?
d. Do you like how the information is presented? What comments or issues do you have?
e. Do you like the words and icons used? What comments or issues do you have?
3. Core questions for the app
a. In a crisis scenario, do you think the design of the app is appropriate?
b. In a crisis scenario, do you think the app will provide you with the needed information?
c. Given that the app may be used during a crisis, would you change how the app looks?
d. Given that the app may be used during a crisis, would you add/remove anything?
e. What would make you uninstall the app?

Data analysis

We used thematic analysis to examine the eighteen interviews. Thematic analysis is a 'method for identifying, analysing and reporting patterns (themes) within data', and a theme 'represents some level of patterned response or meaning within the data set' (Braun and Clarke 2006 p. 80). The study followed Braun and Clarke's (2006) 6-step process. The first step is familiarisation with the data starting with the transcription of the interviews. The second step is generating topics; for this study, we used a theoretical approach by using Tan et al.'s (2018) usability factors as the initial topics: app utility, app dependability, UI graphics, UI output, and UI input. The third step is searching for themes around the initial topics. The fourth step is reviewing themes; this involves refining the themes by collapsing and combining themes as necessary. The fifth step is defining and naming themes. The sixth step is to report the results. We discuss the initial results in the next section.

INITIAL RESULTS AND DISCUSSION

The study is still undergoing the data analysis process. Currently, the study is on step-3, searching for themes. A few themes have already formed (see Table 4). The themes are areas that the interviewees have expressed concern or interest in as they interacted with the app or as they answered the questions from the interview. The themes listed in the table is not yet exhaustive nor is it finalised as the analysis is still ongoing.

Table 4. Initially formed themes

Topics	**Initially formed themes**
App utility	Relevance of the content Clarity of the purpose of the app Frequency of use
App dependability	Accuracy Error-free operation Trust
UI graphics	Disengaged parts White, empty spaces Colour Simplicity/ complexity
UI output	Familiarity Salience of information Interesting/ boring Use of images and text Length of content
UI input	Auto-complete for search User power/control Settings/ customization Intuitiveness

For this working paper, a short discussion based on the findings so far will focus on some insights gathered around the app's interface output. The users' insights showcase the value of collecting user feedback for the design and development of disaster apps.

User insights on the interface output of the app

Interface output is about how well an app presents content effectively (Hoehle and Venkatesh 2015). Through the usability inquiry, we obtained an understanding of users' views and feelings on how the app presented its content.

The participants confirmed comfort and ease when they found familiarity with the interface. The participants found that similarity of the interface to other apps' helpful in using the NZ Alerts app.

> *I appreciate that it looks like an app that I am familiar with. […] It's what I'm used to. Which make me comfortable.* [Participant#05]

> *If people are not used to it, they will find it difficult to use.* [Participant#06]

On the other hand, the participants also raised concern, highlighting that too much similarity has its downside also. For example, a few participants questioned whether they needed to scroll far to get relevant news. Scrolling endlessly to retrieve information is an experience they relate to when using Twitter. Furthermore, participants expressed some concern about presenting information in a feed format, especially in the context of use during disasters.

> *But it can also be a bad thing, as you might need to spend too much time on your phone. Similar to Twitter; if [an organisation] posted something really important. You may have to scroll down really far.* [Participant#03]

> *During a crisis situation, we would be doing a lot of things. There are a lot of notifications – I might miss lots of information that is coming in.* [Participant#04]

Interface output helps with information overload, presentation affects how users perceive information to be compelling or salient (Prasanna et al. 2013; Stratmann and Boll 2016). Beyond raising concern on how critical information will be relayed, participants provided suggestions on how to make information more salient; such as using colours, providing time stamps, and pinning posts, among others.

> *The importance of each post may be different. There could be a generic colour for general things. For alerts, use range of colours, red, orange, yellow*. [Participant#01]

> *I might think the app is out of date. […] Maybe have your own time stamp that says 'this page has been updated 2 minutes ago'.* [Participant#02]

> *If there is a severe alert, there should be a way [for the post] to remain on the top. Even when you scroll, it remains on top.* [Participant#04]

Furthermore, the participants were also able to highlight which elements in the app already helped emphasise critical information.

> *I like how they have the logos [of the authorities] for each. Really helpful, especially when you are scrolling really quick to look for something.* [Participant#15]

NEXT STEPS AND FUTURE WORK

The importance of usability has been emphasised in safety-critical technology research (Kwee-Meier et al. 2017); however, limited comparable literature can be found on public-facing disaster apps. Furthermore, only a small number of academic work have employed user-centred methods in understanding the usability of disaster apps. This study addresses the gaps by highlighting and utilising citizen's feedback to gain insights on usability.

This paper has shown that the intended end-users' perspectives have value to the design and development of the NZ Alerts app. With the partial analysis for a single initial topic (UI output), the insights confirmed some design decisions, supplied particular concerns specific to the disaster context of use, and offered suggestions on improving salience. Through the full analysis of the usability inquiry, more themes will be reviewed and refined; potentially offering a holistic appraisal of the initial app configuration.

The next steps for this study are to complete the analysis of the usability inquiry and to present a comprehensive report of the results. Practical action forward for the NZ Alerts app is to use the results for the next iteration of design and development. Future theoretical work will build on the broader implications of the results; developing a case for a citizen-centric approach in enhancing the usability of disaster apps.

REFERENCES

Bachmann, D. J., Jamison, N. K., Martin, A., Delgado, J., and Kman, N. E. (2015). "Emergency preparedness and disaster response: There's an app for that." *Prehospital and disaster medicine*, 30(5), 1–5.

Bean, H., Liu, B. F., Madden, S., Sutton, J., Wood, M. M., and Mileti, D. S. (2016). "Disaster warnings in your pocket: How audiences interpret mobile alerts for an unfamiliar hazard." *Journal of Contingencies and Crisis Management*.

Biersdorfer, J. D. (2016). "Putting your Twitter feed back in chronological order." *The New York Times*, <https://www.nytimes.com/2016/03/22/technology/personaltech/putting-your-twitter-feed-back-in-chronological-order.html> (Feb. 1, 2019).

Braun, V., and Clarke, V. (2006). "Using thematic analysis in psychology." *Qualitative Research in Psychology*, 3(2), 77–101.

Bromwich, J. E., and Haag, M. (2018). "Facebook is changing. What does that mean for your news feed?" *The New York Times*, <https://www.nytimes.com/2018/01/12/technology/facebook-news-feed-changes.html> (Feb. 1, 2019).

Chang, T., and Chen, J. (2018). "Mobile communication technology and cell broadcast service for emergency alerts in Taiwan." *ISCRAM Asia Pacific 2018 Proceedings - 1st International Conference on Information Systems for Crisis Response and Management Asia Pacific.*, K. Stock and D. Bunker, eds., Wellington.

Estuar, M. R. J., De Leon, M., Santos, M. D., Ilagan, J. O., and May, B. A. (2014). "Validating UI through UX in the context of a mobile-web crowdsourcing disaster management application." *2014 International Conference on IT Convergence and Security*, 0–3.

Falcão, J. D., Krebs, J., Kumar, S., and Erdogmus, H. (2018). "OpenAlerts: A software system to evaluate smart emergency alerts and notifications." *2018 ACM International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers*, Singapore, 1250–1255.

Fischer, H., and Klompmaker, F. (2012). "Enriching disaster control management based on human-centered design." *ISCRAM 2012 Proceedings - 9th International Conference on Information Systems for Crisis Response and Management*, (L. Rothkrantz, J. Ristvej, and Z. Franco, eds.), Vancouver.

Folmer, E., and Bosch, J. (2004). "Architecting for usability: A survey." *Journal of Systems and Software*, 70(1–2), 61–78.

GeoNet. (n.d.). "About GeoNet." <https://www.geonet.org.nz/about> (Feb. 5, 2019).

Gomez, R. Y., Caballero, D. C., and Sevillano, J.-L. (2014). "Heuristic evaluation on mobile interfaces: A new checklist." *The Scientific World Journal*, 1–29.

Gutteling, J. M., Terpstra, T., and Kerstholt, J. H. (2017). "Citizens' adaptive or avoiding behavioral response to an emergency message on their mobile phone." *Journal of Risk Research*, Routledge, 9877, 1–13.

Harrison, R., Flood, D., and Duce, D. (2013). "Usability of mobile applications: Literature review and rationale for a new usability model." *Journal of Interaction Science*, 1(1).

Hiltz, S. R., Van de Walle, B., and Turoff, M. (2010). "The domain of emergency management information." *Information systems for emergency management*, B. Van de Walle, M. Turoff, and S. R. Hiltz, eds., Advance in management information systems, NY, 3–20.

Hoehle, H., and Venkatesh, V. (2015). "Mobile application usability: Conceptualization and instrument development." *MIS Quarterly*, 39(2), 1–12.

Hoehle, H., Zhang, X., and Venkatesh, V. (2015). "An espoused cultural perspective to understand continued intention to use mobile applications: a four-country study of mobile social media application usability." *European Journal of Information Systems*, 24(3), 337–359.

"I imagine most people push OK in a panic to stop the loud sound, and then are left wondering what it was exactly that was so important." (2014). <https://android.stackexchange.com/questions/67354/how-to-recall-or-review-wea-alerts-e-g-amber-alerts> (Feb. 1, 2019).

Iannucci, B., Falcao, J. D., Erdogmus, H., Griss, M., and Kumar, S. (2016). "From alerting to awareness." *IEEE International Conference on Technologies for Homeland Security*, IEEE, 1–6.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015). "Processing social media messages in mass emergency: A survey." *ACM Computing Surveys*, 47(4), 1–38.

Kaufhold, M.-A., Rupp, N., Reuter, C., Amelunxen, C., and Cristaldi, M. (2018). "112.Social: Design and evaluation of a mobile crisis app for bidirectional communication between emergency services and citizens." *26th European Conference on Information Systems (ECIS 2018)*, Portsmouth, UK.

Kolathayar, S., Kumar, V. K., Rohith, V. R., Priyatham, K., Nikil, S., and Anupa, S. A. (2018). "Development of mobile application to assess and enhance earthquake preparedness level of individuals and community in India." *Sustainable Design and Construction for Geomaterials and Geostructures. GeoChina 2018. Sustainable Civil Infrastructures.*, B. Fatahi and D. Mwanza, AChang, eds., Springer, Cham, 197–216.

Kuula, J., Kettunen, P., Auvinen, V., Viitanen, S., Kauppinen, O., and Korhonen, T. (2013). "Smartphones as an alerting, command and control system for the preparedness groups and civilians: results of preliminary tests with the Finnish Police." *ISCRAM 2013 Proceedings - 10th International Conference on Information Systems for Crisis Response and Management*, T. Comes, F. Fiedrich, S. Fortier, J. Geldermann, and T. Muller, eds., Baden-Baden, 42–51.

Kwee-Meier, S. T., Wiessmann, M., and Mertens, A. (2017). "Integrated information visualization and usability of user interfaces for safety-critical contexts." *Lecture Notes in Computer Science*, D. Harris, ed., 71–85.

"Last night I got an emergency alert. I didn't have my glasses on and as I reached for the phone, I lost the message. How can I find that message? Thanks." <https://discussions.apple.com/thread/5417200> (Feb. 1, 2019).

MetService. (n.d.). "The MetService app - it's your everyday weather app." <https://about.metservice.com/our-company/ways-to-get-the-weather/weather-on-your-mobile/nz-weather-app/> (Feb. 5, 2019).

Ministry of Civil Defence and Emergency Management. (n.d.). "Emergency Mobile Alert frequently asked questions (FAQ)." <https://www.civildefence.govt.nz/get-ready/civil-defence-emergency-management-alerts-and-warnings/emergency-mobile-alert/emergency-mobile-alert-frequently-asked-questions-faq/> (Feb. 2, 2019).

Ministry of Civil Defence and Emergency Management. (2017). *Emergency Mobile Alert: Protocol for user agencies*.

Mohan, L., Mathur, N., and Reddy, Y. R. (2015). "Mobile App Usability Index (MAUI) for improving mobile banking adoption." *Evaluation of Novel Approaches to Software Engineering (ENASE), 2015 International Conference on*, 715, 313–320.

National Academies of Sciences Engineering and Medicine. (2018a). "A research agenda." *Emergency alert and warning systems: Current knowledge and future research directions*, Washington DC, 56–73.

National Academies of Sciences Engineering and Medicine. (2018b). "Understanding public response to alerts and warnings." *Emergency alert and warning systems: Current knowledge and future research directions*, The National Academies Press, Washington DC, 18–44.

New Zealand Red Cross. (2015). "New Hazard app helps Kiwis prepare for and survive disasters." *New Zealand Red Cross*, <https://www.redcross.org.nz/documents/57/Hazard_app_press_release.pdf> (May 4, 2016).

Nurse, J., Creese, S., and Goldsmith, M. (2012). "An initial usability evaluation of the secure situation awareness system." *ISCRAM 2012 Proceedings - 9th International Conference on Information Systems for Crisis Response and Management*, L. Rothkrantz, J. Ristvej, and Z. Franco, eds., Vancouver.

Petersen, K., Büscher, M., Kuhnert, M., Schneider, S., and Pottebaum, J. (2015). "Designing with users: Co-design for innovation in emergency technologies." *ISCRAM 2015 Proceedings - 12th International Conference on Information Systems for Crisis Response and Management*, (L. Palen, M. Buscher, T. Comes, and A. Hughes, eds.), Kristiansand.

Potter, S. H. (2018). *Recommendations for New Zealand agencies in writing effective short warning messages*. GNS Science, Lower Hutt.

Prasanna, R., Yang, L., and King, M. (2013). "Guidance for developing human-computer interfaces for supporting fire emergency response." *Risk Management*, 15(3), 155–179.

Reuter, C., Kaufhold, M.-A., Leopold, I., Knipp, H., and Kaufhold, M.-A. (2017). "Katwarn, NINA, or FEMA? Multi-method study on distribution, use, and public views on crisis apps." *25th European Conference on Information Systems (ECIS)*, Guimaraes, Portugal, 2187–2201.

Romano, M., Onorati, T., Aedo, I., and Diaz, P. (2016). "Designing mobile applications for emergency response: Citizens acting as human sensors." *Sensors*, 16(3), 1–17.

Sarshar, P., Nunavath, V., and Radianti, J. (2015). "On the usability of smartphone apps in emergencies: An HCI analysis of GDACSmobile and SmartRescue apps." *Lecture Notes in Computer Science*, (L. Palen, M. Buscher, T. Comes, and A. Hughes, eds.), University of Agder (UiA), 9170, [1-6].

Schnall, R., Rojas, M., Bakken, S., Brown, W., Carballo-Dieguez, A., Carry, M., Gelaude, D., Mosley, J. P., and Travers, J. (2016). "A user-centered model for designing consumer mobile health (mHealth) applications (apps)." *Journal of Biomedical Informatics*, Elsevier Inc., 60, 243–251.

Stratmann, T. C., and Boll, S. (2016). "Demon hunt - The role of Endsley's demons of situation awareness in maritime accidents." *Human-centered and error-resilient systems development*, C. Bogdan, J. Gulliksen, S. Sauer, P. Forbrig, M. Winckler, C. Johnson, P. Palanque, R. Bernhaupt, and F. Kis, eds., Stockholm, 203–212.

Tan, M. L., Prasanna, R., Hudson-Doyle, E., Stock, K., Johnston, D., and Leonard, G. (2018). "Usability factors affecting the continuance intention of disaster apps." *ISCRAM Asia Pacific 2018 Proceedings - 1st International Conference on Information Systems for Crisis Response and Management Asia Pacific.*, K. Stock and D. Bunker, eds., Wellington, 326–338.

Tan, M. L., Prasanna, R., Stock, K., Hudson-Doyle, E., Leonard, G., and Johnston, D. (2017). "Mobile applications in crisis informatics literature: A systematic review." *International Journal of Disaster Risk Reduction*, 24, 297–311.

Theunissen, M. (2017). "Emergency mobile alert system launching." *NZ Herald*, <https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11943062>.

Veil, S. R., Buehner, T., and Palenchar, M. J. (2011). "A work-in-process literature review: incorporating social media in risk and crisis communication." *Journal of Contingencies and Crisis Management*, 19(2), 110–122.

"Where are emergency alerts (WEA) stored on the iPhone? One popped up and disappeared before I could read it." (2013). <https://discussions.apple.com/thread/4785646> (Feb. 1, 2019).

Wright, K. C., Leonard, G., Beatson, A., Morris, B., O'Sullivan, R., Coomer, M. A., and Freire, D. (2014). *Public Alerting Options Assessment: 2014 update*. GNS Science, Lower Hutt.

Zapata, B. C., Fernández-Alemá, J. L., Idri, A., and Toval, A. (2015). "Empirical studies on usability of mHealth apps: A systematic literature review." *Journal of Medical Systems*, 39(2), 1–19.

Zhang, D., and Adipat, B. (2005). "Challenges, methodologies, and issues in the usability testing of mobile applications." *International Journal of Human-Computer Interaction*, 18(3), 293–308.

Predicting Hurricane Damage Using Social Media Posts Coupled with Physical and Socio-Economic Variables

Guoqin Ma
Stanford University*
sebsk@stanford.edu

Chittayong Surakitbanharn†
Stanford University
jao@stanford.edu

ABSTRACT

During a natural disaster or emergency event, individual social media posts or hot spots may not necessarily correlate to the most devastated areas. To better understand the correlation between social media and physical damage, we compare Tweets, data about the physical environment, and socio-economic factors with insurance claim information (as a proxy for physical damage) from 2017 Hurricane Irma in the state of Florida. We use machine learning to identify relevant Tweets, sensitivity analyses to identify socio-economic factors, and statistical regression to determine the predictive capability of insurance claims as a proxy for damage. We find that Tweets alone result in a poorly fitted regression model of insurance claims, but the inclusion of physical features (e.g., power outages, wind level) and socio-economic factors (e.g., population density, education, Internet access) improves the model's fit. Such models contribute to the knowledge base that may allow social media to predict damage in real-time.

Keywords

Social media, disaster management, damage prediction

INTRODUCTION

The rise of social media over the past 15 years has marked a shift in the potential of how information is collected and disseminated during natural disasters (Reuter and Kaufhold 2018). The flow of information between authorities, like emergency managers and first-responders, and the broader community is becoming increasingly bi-directional. A person with an internet connection in the wake of a flood, wildfire, earthquake, or hurricane now has the ability to ask for help or report damage via Twitter, Facebook, Instagram, or another platform (Jurgens and Helsloot 2018).

The messages conveyed by social media may help people identify the most devastated areas before conventional post disaster damage assessments (Kryvasheyeu, H. Chen, Obradovich, et al. 2016; Resch et al. 2018). With knowledge of these areas, a decision maker may deploy personnel, aid, or other resources based on the singular post or "hot-spot" of posts (Gao et al. 2011). However, identifying areas most in need requires the filtering of social media content to identify the most relevant information (Leykin et al. 2018). Moreover, basing resource allocation decisions on social media posts may not necessarily serve communities posting the most (e.g., those whom have internet connection during a disaster) rather than those most at-need (Brynielsson et al. 2018).

Although researchers have correlated Twitter activity to economic damage (Kryvasheyeu, H. Chen, Obradovich, et al. 2016), an ongoing challenge in using social media for disaster management is addressing why a certain region may be more active on social media during a disaster. For example, social media posts may correspond with areas with younger populations that have higher social media adoption rates and not capture of elderly communities (Perrin 2015). Certain regions may have higher levels of internet connectivity resulting in more social media activity. Non-English speaking communities may be using other communication platforms aside from the ones monitored by authorities. Without understanding and accounting for biases is how posts are generated, using social media for disaster response may favor areas with higher adoption rates.

*http://urbanresilience.stanford.edu
†corresponding author

Our goal is to determine the relationship between a sample of Twitter posts and insurance claims as a proxy for on-the-ground damage, while adjusting for demographic and physical factors that could impact a geographic area's ability to Tweet. To do so, we first test and apply machine learning based classification and filtering methods to Tweets from 2017 Hurricane Irma. Then, we apply a regression to estimate the relationship between filtered Tweets and insurance claims in Florida resulting from the hurricane. Further, we test how incorporating physical features (e.g., power outages, Internet access) and demographic/socioeconomic factors (e.g., population density, education, age, etc.) impact the model's fit.

BACKGROUND

Researchers have tested whether social media can be used for disaster management through outbreak detection (Earle et al. 2011, Kryvasheyeu, H. Chen, Moro, et al. 2015), information retrieval (Imran, Elbassuoni, et al. 2013), sentiment analysis (Stieglitz et al. 2018, Kryvasheyeu, H. Chen, Moro, et al. 2015), evacuation behavior (Stowe, Anderson, et al. 2018, Danaë Metaxa-Kakavouli et al. 2018), hazard assessment (Resch et al. 2018, Burks et al. 2014, Herfort et al. 2014), and damage assessment (Resch et al. 2018, Kryvasheyeu, H. Chen, Obradovich, et al. 2016, Guan and C. Chen 2014). By combining methods of prior work, our efforts to test Twitter's capability for damage assessment first requires determining what information is relevant and filtering that information. The second step requires providing context to how that information exists. In other words, what populations do the social media posts represent and can it be trusted and be representative? Finally, an actionable decision responding to the local damage assessment should be able to be made considering all factors mentioned above.

Filtering

Keyword-based filtering is a technique to select disaster-related Tweets, where the quality of the filtered Tweets depends on the keywords researchers or practitioners choose. Yet, keyword filtering may not be enough to eliminate noise from information (Leykin et al. 2018), which has led to the development of machine learning algorithms to better identifying disaster related Tweets (Li, D. Caragea, C. Caragea, and Herndon 2018; Mazloom et al. 2018; Li, D. Caragea, and C. Caragea 2017; Stowe, Paul, et al. 2016).

For example, Resch and colleagues (2018) developed a Latent Dirichlet Allocation (LDA) algorithm to determine the earthquake-related Tweets and damage-related Tweets in the 2014 Napa earthquake in California. However, their algorithm still requires extensive human involvement to identify the topics that the LDA generates. Imran and colleagues (2016) and Alam and colleagues (2018) tested Tweets classification tasks with deep learning, but their models, have not been utilized in any case study to perform damage assessment. We expand upon this prior work through testing new filtering techniques through combining keyword filtering, neural net Tweets classification, and sentiment cut-off.

Bias

Prior research focuses on correlating Tweet activity and disaster damage, such as the comparison of Tweets and earthquake-related physical variables to estimate earthquake ground shaking intensity (Burks et al. 2014), without study into who is generating the Tweets. Twitter user patterns may be skew to disproportionately represent certain segments of a population. Prior research has shown that older populations have less social media adoption compared to younger counterparts (Perrin 2015). Areas with limited internet connectivity are less represented in social media compared to urban population centers (Mislove et al. 2011). English is the main language involved in disaster social media texts classification machine learning training, such as from CrisisLex (Olteanu, Castillo, et al. 2014) and CrisisNLP (Imran, Mitra, et al. 2016) data sets. Minority ethnic groups typing different languages may be overlooked when researchers focus on English Twitter posts.

To build upon prior work, we include physical variables and societal factors to test whether they improve a social media based regression model's prediction of physical damage. Specifically, we build a Tweets-based regression model incorporating other correction factors to estimate county-level damage (in terms of number of claims). By doing so, we work towards the quantitative usage of Tweets in disaster damage assessment while adjusting for biases in how the Tweets are generated.

METHODS

The foundation of this paper is to determine the relationship between geo-tagged Tweets from Florida during 2017 Hurricane Irma and the geographic distribution of post-disaster insurance claims resulting from the event. We then

aim to understand if the predictive ability of Twitter data could be improved through incorporating socio-economic factors that may have better reflected those the communities generating the Tweets.

We first apply machine learning techniques to classify and filter the Tweets. Second, we conduct a sensitivity analysis to select socio-economic factors that may affect the ratio between disaster-informative Tweets density and post-disaster claims percentage. Third, we determine the relationship of the Tweets, socio-economic factors, and insurance claims by fitting the data into regression models.

For this study, we use 201,833 geo-tagged Tweets from Florida during Hurricane Irma are collected from August 21, 2017 to September 14, 2017. This timeframe encompasses when Hurricane Irma made landfall in Florida around September 10 and 11. County level insurance claim data is collected from Florida Office of Insurance Regulation (2018). Socio-economic data was accessed from an aggregate dataset based on information from the 2010 Census among others (Kirkegaard 2016).

Tweet Filtering by Keywords, LSTM, and Sentiment Analysis

To pre-process the data, the Tweets first are made lowercase and retweets such as "RT @:NAME", HTMLs, smiley faces and emojis are removed. Stop-word (some most common words in a language), are not removed because words such as "not" may affect sentiment analysis in the later filtering layer. We also do not perform lemmatization (return the base or dictionary form of a word), to facilitate the use of pretrained word embeddings. Hashtags (the words after "#") are not removed because they might indicate the topic of the Tweet. After the pre-processing, duplicates Tweets are removed from the data. The pre-processed Tweets are first filtered by the keywords including *hurricane*, *irma*, *flood*, *cyclone*, *storm*, *wind*, and *typhoon*.

Second, we use prior sets of labeled Tweets to train a neural network model to classify the level of relevance for each Tweet from our Hurricane Irma dataset. We apply Bidirectional Long-Short Term Memory (LSTM) recurrent neural network due to the potential to select Tweets more relevant to Hurricane Irma compared to simple keyword filtering (Leykin et al. 2018). We use prior English language crisis related Tweets that are previously labeled (Table 1) as training datasets.

Generally there are two types of supervised learning labels in disaster Tweets classification: relatedness and informativeness. Relatedness-based classification resembles a keyword-search whereas informativeness-based classification aims more at finding Tweets useful to humanitarian aid organizations or governments to take action. We apply the criteria for informativeness based of prior definitions as providing information that is useful to a person (Truong et al. 2014; Olteanu, Vieweg, et al. 2015). For example, a Tweet that states *This hurricane sandy twitter is so annoying* would not be considered informative (Truong et al. 2014). Informative Tweets fall in one of the following categories: affected individuals, infrastructure and utilities damage, sympathy and support, caution and advice, donation and volunteering other useful information. Further, the type of hazard in the training datasets greatly impacts the performance of the classifier (Li, D. Caragea, C. Caragea, and Herndon 2018). Therefore, we attempt to make the classifier hurricane-specific by choosing only hurricane and floods events from the available Tweet training datasets.

Table 1. Tweet Training Datasets

Database	Dataset	Reference
CrisisLex	T6 and T26	Olteanu, Castillo, et al. 2014
CrisisNLP	#1	Imran, Mitra, et al. 2016
CrisisNLP	#2,#3	Imran, Elbassuoni, et al. 2013
CrisisNLP	#6	Alam, Ofli, et al. 2018

Third, we classify whether the Tweets have a positive (>0, max 1) or negative (<0, min -1) sentiment using the `Python` library `textblob`. We chose to only keep Tweets with a sentiment of less than zero based on our quantitative analysis that negative Tweets generally exhibited higher levels of correlation to post-Irma insurance claims compared to Tweets of zero or positive sentiment. However, there are other interpretations of sentiment that is suitable for predicting disaster damage that we do not address here. For example, it is a separate issue to explain whether people with disaster damage are exhibiting more positive (hopeful) or negative (glum) sentiments post disaster.

The remaining Tweets are parsed at a county level to match the insurance claim data granularity. The Tweet count was then divided by county population to calculate Tweets per capital.

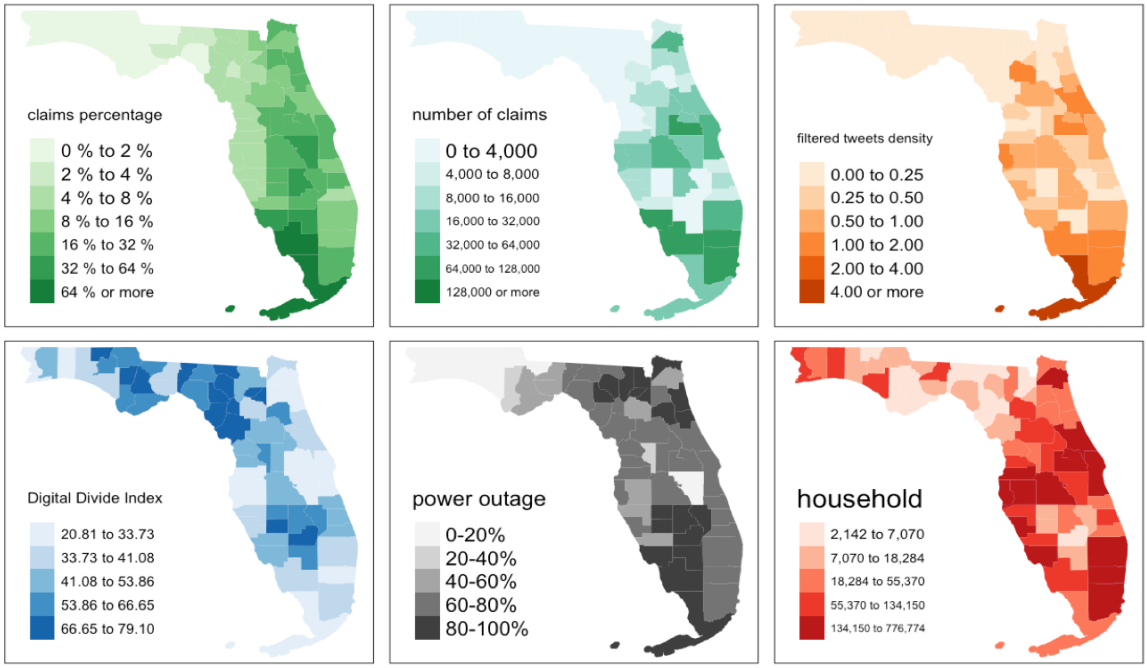


Figure 1. Example variables mapped at county level in Florida. Clockwise from the top left: Percentage of insurance claims per total number of households in the county, absolute value of insurance of claims, filtered Irma-informative tweets with negative sentiment per 10,000 population, Digital Divide Index as a proxy for internet connectivity, peak percent power outage on Sept 11, number of households.

Incorporating Socio-economic Factors and Insurance Claim Data

Social media may under-represent or over-represent different demographics due to varying levels of adoption (Mislove et al. 2011). To account for such variability, we identify demographic and socio-economic factors that may potentially explain the generation of Tweets and test whether their inclusion into the regression model improves the prediction of insurance claims.

To determine factors that are statistically relevant to insurance claims or affecting Twitter activity, a sensitivity analysis is applied to Irma insurance claims data, filtered Tweets per capita, power outage data at the county level, as well as approximately 70 demographic and socio-economic factors including ethnicity, age, income, education, household type, Internet access, and occupation. Claims data are extracted from the publication of Florida Office of Insurance Regulation (Florida Office of Insurance Regulation 2018). The demographic and socio-economic factors are obtained from the R-package "USA.county.data" (Kirkegaard 2016) and the US Census Bureau (2000). Internet connectivity data are attained from the Digital Divide Index (DDI) (Intelligent Community Institute 2017). Power outage data are attained from the US Energy Information Administration (US Energy Information Administration 2017). Wind speed, a binary categorical variable indicating whether the wind level is hurricane or tropical storm when Irma swept the county, is retrieved from a news report (Washington Post 2017). Example variables are illustrated in Figure 1.

We first exclude factors that are highly correlated (correlation 0.6 or above). For example, the two variables "percentage of people with at least a bachelor's degree" and "percentage of people with at least a master's degree" are highly correlated so only "percentage of people with at least bachelor's degree" is kept. We take such action as a measure to prevent multicollinearity.

We use random forest and distance-based sensitivity analysis (DGSA) to select predictor variables of the regression model. We use the metric "Increase in MSE" (IncMSE) to check the sensitivities in random forest. Two sensitivity analyses are conducted, each with a different response variable, namely claim percentage (number of claims normalized by number of households at county level) and ratio between filtered Tweets per capita and claim percentage. The former explores which factors may affect claims report in each county, while the latter tests which factors may explain the bias of using social media as a damage indicator.

Regression

A negative binomial regression with *number of claims* as dependent variable is created and evaluated based on *RMSE*. We model the "rate" of claims using *number of households* as the offset. The canonical *Moran I* Monte Carlo test (with 2000 simulations) checks spatial auto-correlation. Tweets, the demographic and socio-economic factors chosen from the sentiment analysis, power outages, and categorical wind speeds are included in the regression analysis. The zero-inflated negative binomial model estimates Tweets density in each county to look for the dominant factors affecting Twitter users' activity. In this regression analysis, Tweets count is the dependent variable (offset is population) while claims percentage belongs to one of the independent variables.

RESULTS

Tweet Filtering by Keywords, LSTM, and Sentiment Analysis

21,307 Tweets remain after the keyword filtering. In the next step, the pre-trained Tweet classifier selected related and informative Tweets from the set of 21,307 filtered by keywords. The relatedness-classifier attained 94.9% test accuracy with a training dataset of 16,000 Tweets, validation dataset of 5,000 Tweets, and test dataset of 5,000 Tweets. The informativeness-classifier had 32,000 Tweets of training data, 5,000 validation Tweets, and 5,000 test Tweets to attain 82.4% test accuracy. We choose to use the informativeness-based classifier to filter the Irma Tweets. 13,216 Tweets remain after applying the informativeness-classifier. 1,745 Tweets remain after applying the sentiment analysis.

Sensitivity Analysis and Regression

Factors such as *filtered tweets in 10 thousand people*, *power outage*, *Latino population*, *NBBND* ("percent of population without access to 25[Mbs download]/3(Mbs upload] fixed broadband," an indicator of local Internet access), and *UPS* (upload speed) play an important role in random forest regression with claims as the dependent variable. The random forest in Figure 2 shows that population over age 65, population density, school enrollment, races, internet access are significant to sway the ratio between Tweets and claims, while power outage is not significant.

Table 2. Negative Binomial Regression

Predictors	RMSE (claims %)	Moran I	Pseudo R-squared
Tweets only	14.71	0.0005	0.2588
power outage only	14.84	0.0005	0.2394
Tweets + power outage	12.35	0.0005	0.5536
Tweets + UPS + power outage	14.40	0.1224	0.6569
Tweets + UPS + power outage + wind	11.2	0.2529	0.7001
Tweets + UPS + Latino pop + power outage	9.84	0.0760	0.7000
Tweets + UPS + Latino pop + power outage + wind	10.11	0.1279	0.7122

The negative binomial regression is summarized in Table 2 and the coefficients of each term are given in Table 3. The zero-inflated negative binomial model is summarized in Table 4. Population density, school enrollment and claim percentage contribute positively to local Tweets density and NBBND (percent of 2010 population without access to 25/3 fixed broadband) explains the excessive zeros in the local Tweets density variable.

Table 3. Negative Binomial Regression Coefficients

Predictors	Coef.	p-value
log(filtered Tweets per 10,000 population)	0.10260	0.011673
power outage 40%-60%	0.38487	0.187015
power outage 60%-80%	0.92931	0.000152
power outage 80%-100%	1.96994	6.44e-15
log(UPS)	0.43172	0.000142
log(Latino population)	0.26240	0.084085
wind (Tropical storm)	-0.40955	0.107919

Table 4. Zero-Inflated Negative Binomial Model: the variables above are the count model coefficients; the variable below is the zero-inflation model coefficient

Predictors	Coef.	p-value
population density	4.454e-04	0.000304
school enrollment	1.063e-01	0.004693
claim percentage	3.175e-02	1.12e-07
log(NBBND15+1)	1.8394	0.00367

DISCUSSION

Our initial study demonstrates that incorporating demographic as physical factors could improve the prediction of a regression model, as demonstrated by the improved pseudo-R^2 fit in Table 2 to a value of around 0.7. More importantly, our study highlighted the challenges in fusing multiple streams of crisis informatics research, including classification, data integration, and prediction, to create a system of social media use for real time damage assessment.

Machine Learning Classifier

Although relatedness-based classification has a higher accuracy, it may be more meaningful to classify the Tweets using informativeness-based classification. The drawback of using the relevance classification is that some messages may be on-topic but it conveys nothing useful for disaster response. For example: *these hurricane sandy tweets are so hilarious tho* is an on-topic, but not informative Tweet extracted from CrisisLexT6 Hurricane Sandy dataset. However, the drawback of informativeness classification criterion is that its boundary of classification is blurry and subjective, which leads to low accuracy.

Sentiment Analysis

In sentiment analysis, the cut-off *<0* returned the highest correlation. A potential explanation is that negative sentiment could reflect hurricane damage better than neutral and positive Tweets. The drop in correlation with further decrease in sentiment cut-off might be due to too few Tweets included in analysis losing the power of representation.

There are also questions about the accuracy of `Textblob` since it is not specialized in disaster Tweets. At this stage, the sentiment analyzer is a "black box" which is plugged into the workflow. A more sentiment classifier specialized in disaster message could improve the sentiment analysis. Additionally, the sentiment analysis removed nearly 90 % of keyword and machine learning filtered Tweets and left a data-set of only 1,745 Tweets to analyze for the entire state of Florida. Future tests without the sentiment analysis can help determine whether there is any value in applying the sentiment analyzer.

Sensitivity Analysis and Regression

We did not do train-test split to the county-level data due to data limitations. The data available to us were the geo-tagged Tweets in Florida and claim data at county level, which was not enough to validate the model or to do extensive study on the impact of different classification techniques since the conclusions might over-fit the Hurricane Irma case. The regression models are explanatory instead of predictive.

We found that by including demographic and socio-economic factors could improve the performance of the model compared with only including Tweets variable itself. Tweets, Latino population, Internet access metrics (NBBND (percent of population with no access to fixed broadband), UPS (upload speed)), as well as power outage are the most significant indicators. Prior to the regression, we hypothesized that Tweets and power outage were the main predictors and that UPS and Latino population were the correction terms. More Tweets or higher power outage percentage would imply higher claim percentage. The coefficient of UPS was expected to be negative because UPS could serve as a correction to the bias of using social media: more Tweets would be naturally generated in counties with better Internet connectivity.

The coefficient of Latino population was expected to be positive because the Tweets we analyzed only English Tweets and Latino Population could compensate for the Spanish Tweets. The reason that Latino population was more sensitive than other population is that Spanish is the second most popular language used in Florida (Statistical Atlas 2018) while other languages are less prevalent.

The regression results support our expectation on all the variables except for UPS, the sign of coefficient of which is positive. We suspect it is because that UPS could represent the urbanization of counties. In an urbanized county, the homeowner insurance is more widely covered. Power outage is an important indicator for possibly two reasons: first, it indicates damage brought by Hurricane Irma, and second, it corrects the filtered Tweets variable since high power outage percentage would impede people from using their cell phone or other electronic devices. The sole power outage predictor could fit the claim data better than what the sole Tweets predictor could achieve (except the regression tree). A model using the two power and Tweets data simultaneously best fit the claim data.

The zero inflated negative binomial models shows that NBBND (percent of 2010 population without access to 25/3 fixed broadband) accounts for the excessive zeros in Tweets count, which means regions with poor internet access have less active Twitter users. Beside claim percentage, population density, which indicates populous urban environment, also plays a role in the model. The variable school enrollment is another indicator of development as well (Gennaioli et al. 2013). The absence of power outage in both random forest and zero negative binomial regression models implies that Twitter users may not be heavily affected by power outage and the power outage variable in the former regression models only implies physical damage but no compensation for the Tweets bias. However, since the Tweets count is aggregate throughout the whole period and is at county level, it is hard for us to capture the impact of power outage on Twitter activity.

More Tweets-based features will be explored once we can go beyond binary classification. Different information types may be related to local claims differently. We are also actively looking for claims data with higher granularity and an exhaustive collection of Tweets so that more data points could be leveraged in regression analysis so that we can come up with a better model and a better explanation of the connections between variables. We are also looking for data from another hurricane disaster to test how our model can be generalized. Besides, we will also explore the ability of Tweets to do a quick and reliable estimation of disaster damage by controlling the temporal duration of Tweets that are included in the analysis.

Limitations

Many variables are sensitive in sensitivity analysis but not significant in regression. The impact might be nonlinear and data might not be enough to obtain the true significance. Some variables are not sensitive perhaps because their range is not wide. For example, in Pew Research Center's report (Perrin 2015), females tend to use social media more frequently than males. However, gender was not significant in sensitivity analysis. The range of female percent is not wide (1st quantile - 3rd quantile: 49.9 - 51.5), which shows the female percent does not vary significantly among counties.

In this paper, we assume a monotonic relationship between Tweets density and claims percentage, which is open to discussion. Questions such as how the Tweets may trigger false alarm (local residents thought danger would come but the hurricane derailed later) are not considered. Considering 200,000 Tweets are a small sample of the total Tweets in this time period in Florida, we do not perform temporal analysis.

Because the sensitivity analysis and regression is done on the county level, we do not take the impacts of evacuation on Tweet generation into consideration for the scope of this paper. It is assumed that evacuation occurred within county. Monroe County is an exception, where the entire county was issued a mandatory evacuation order. However, we find considerable Tweets in Monroe throughout the time span, so we keep Monroe in our analysis.

Since this work was conducted using a sample dataset of geotagged Tweets, the initial classification result of filtered Tweets may be considered rather low in quantity (13,216) and accuracy (0.82). In the future, one possibility to increase coverage is to use the full Twitter "firehose" of Tweets, and georeference additional location information such as the mentioning of specific locations in the Tweet text. Further, the inclusions and parallel analysis of Tweets in other common languages, such as Spanish, may impact the social media based prediction. Accuracy may be improved by refining the annotation task for the training datasets. Although we take insurance claims as measure for damage, it is also important for future work to assess the distribution in insurance coverage and what inherent biases exist for claim request. Finally, demographic and socio-economic factors from 2010 US Census may not reflect the current demographics of Florida.

CONCLUSION

As an initial study, we built a bidirectional-LSTM network to filter disaster-informative Tweets. We studied Tweet feature selection and chose disaster-informative Tweets with negative sentiment to indicate damage level. Sensitivity analysis showed Tweets, Latino population, and upload speed (or some equivalent indicators to internet access) were significant predictors to insurance claims after Hurricane Irma in Florida. Internet access indicators and

urbanization indicators could explain the bias in social media users' representation of the whole population. A non-binomial regression model combining Twitter data, power outage data and social factors best fit insurance claim data.

REFERENCES

Alam, F., Joty, S., and Imran, M. (2018). "Graph Based Semi-supervised Learning with Convolution Neural Networks to Classify Crisis Related Tweets". In:

Alam, F., Ofli, F., Imran, M., and Aupetit, M. (2018). "A Twitter Tale of Three Hurricanes: Harvey, Irma, and Maria". In: *the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*. Rochester, USA.

Brynielsson, J., Granåsen, M., Lindquist, S., Narganes Quijano, M., Nilsson, S., and Trnka, J. (2018). "Informing crisis alerts using social media: Best practices and proof of concept". In: *Journal of Contingencies and Crisis Management* 26.1, pp. 28–40.

Burks, L., Miller, M., and Zadeh, R. (2014). "Rapid Estimate Of Ground Shaking Intensity By Combining Simple Earthquake Characteristics With Tweets". In: *Tenth U.S. National Conference on Earthquake Engineering*. Anchorage, AK, USA.

Danaë Metaxa-Kakavouli, Paige Maas, and Daniel P. Aldrich (2018). "How Social Ties Influence Hurricane Evacuation Behavior – Facebook Research". In: *the ACM on Human-Computer Interaction* 2.

Earle, P. S., Bowden, D. C., and Guy, M. (2011). "Twitter earthquake detection: Earthquake monitoring in a social world". In: *Annals of Geophysics* 54.6, pp. 708–715.

Florida Office of Insurance Regulation (2018). *Hurricane Irma Claims Data*.

Gao, H., Barbier, G., and Goolsby, R. (2011). "Harnessing the crowdsourcing power of social media for disaster relief". In: *IEEE Intelligent Systems*.

Gennaioli, N., Porta, R. L., Lopez-De-Silanes, F., and Shleifer, A. (2013). "Human Capital and Regional Development". In: *The Quarterly Journal of Economics* 128.1, pp. 105–164.

Guan, X. and Chen, C. (2014). "Using social media data to understand and assess disasters". In: *Natural Hazards*.

Herfort, B., Albuquerque, J. P. d., Schelhorn, S.-J., and Zipf, A. (2014). "Twitter Analysis of River Elbe Flood". In: *International Conference on Information Systems for Crisis Response and Management*. Pennsylvania, USA.

Imran, M., Elbassuoni, S., Castillo QCRI, C., Diaz, F., and Meier QCRI, P. (2013). "Extracting Information Nuggets from Disaster-Related Messages in Social Media". In: *the 10th International ISCRAM Conference*. Ed. by T. Comes, F. Fiedrich, S. Fortier, J. Geldermann, and T. Müller. Baden-Baden, Germany, p. 791.

Imran, M., Mitra, P., and Castillo, C. (2016). "Twitter as a Lifeline: Human-annotated Twitter Corpora for NLP of Crisis-related Messages". In: *the 10th Language Resources and Evaluation Conference (LREC)*.

Intelligent Community Institute, M. S. U. (2017). *Digital Divide Index*.

Jurgens, M. and Helsloot, I. (2018). "The effect of social media on the dynamics of (self) resilience during disasters: A literature review". In: *Journal of Contingencies and Crisis Management* 26.1, pp. 79–88.

Kirkegaard, E. (2016). "Inequality across US counties: an S factor analysis". In: *Open Quantitative Sociology and Political Science*.

Kryvasheyeu, Y., Chen, H., Moro, E., Van Hentenryck, P., and Cebrian, M. (2015). "Performance of social network sensors during Hurricane Sandy". In: *PLoS ONE*.

Kryvasheyeu, Y., Chen, H., Obradovich, N., Moro, E., Van Hentenryck, P., Fowler, J., and Cebrian, M. (2016). "Rapid assessment of disaster damage using social media activity". In: *Science Advances*.

Leykin, D., Lahad, M., and Aharonson-Daniel, L. (2018). "Gauging urban resilience from social media". In: *International Journal of Disaster Risk Reduction*.

Li, H., Caragea, D., and Caragea, C. (2017). "Towards Practical Usage of a Domain Adaptation Algorithm in the Early Hours of a Disaster". In: *the 14th ISCRAM Conference*. Ed. by Tina Comes, Frédérick Bénaben, Chihab Hanachi, Matthieu Lauras, and Aurélie Montarnal. Albi, France.

Li, H., Caragea, D., Caragea, C., and Herndon, N. (2018). "Disaster response aided by tweet classification with a domain adaptation approach". In: *Journal of Contingencies and Crisis Management* 26.1, pp. 16–27.

Mazloom, R., Li, H., Caragea, D., Imran, M., and Caragea, C. (2018). "Classification of Twitter Disaster Data Using a Hybrid Feature-Instance Adaptation Approach". In: *the 15th ISCRAM Conference*. Ed. by Kees Boersma and Brian Tomaszewski. Rochester, NY, USA.

Mislove, A., Lehmann, S., Ahn, Y.-Y., Onnela, J.-P., and Rosenquist, J. N. (2011). "Understanding the Demographics of Twitter Users". In: *the Fifth International AAAI Conference on Weblogs and Social Media*.

Olteanu, A., Castillo, C., Diaz, F., and Vieweg, S. (2014). "CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises". In: *Proc. of the 8th International Conference on Weblogs and Social Media*, p. 376.

Olteanu, A., Vieweg, S., and Castillo, C. (2015). "What to Expect When the Unexpected Happens: Social Media Communications Across Crises Human Factors; Measurement". In: *CSCW*. Vancouver, BC, Canada: ACM.

Perrin, A. (2015). *Social Media Usage: 2005-2015*. Tech. rep. Pew Research Center.

Resch, B., Usländer, F., and Havas, C. (2018). "Combining machine-learning topic models and spatiotemporal analysis of social media data for disaster footprint and damage assessment". In: *Cartography and Geographic Information Science* 45.4, pp. 362–376.

Reuter, C. and Kaufhold, M.-A. (2018). "Fifteen years of social media in emergencies: A retrospective review and future directions for crisis Informatics". In: *Journal of Contingencies and Crisis Management* 26.1, pp. 41–57.

Statistical Atlas (2018). *Languages in Florida*.

Stieglitz, S., Bunker, D., Mirbabaie, M., and Ehnis, C. (2018). "Sense-making in social media during extreme events". In: *Journal of Contingencies and Crisis Management* 26.1, pp. 4–15.

Stowe, K., Anderson, J., Palmer, M., Palen, L., and Anderson, K. (2018). "Improving Classification of Twitter Behavior During Hurricane Events". In: *the 6th International Workshop on Natural Language Processing for Social Media*. Melbourne, Australia, pp. 67–75.

Stowe, K., Paul, M., Palmer, M., Palen, L., and Anderson, K. (2016). "Identifying and Categorizing Disaster-Related Tweets". In: *The Fourth International Workshop on Natural Language Processing for Social Media*. Austin, TX, USA.

Truong, B., Caragea, C., Squicciarini, A., and Tapia, A. H. (2014). "Identifying valuable information from twitter during natural disasters". In: *Proceedings of the American Society for Information Science and Technology* 51.1, pp. 1–4.

US Census Bureau (2000). *Florida Census Data: Households and Families*.

US Energy Information Administration (2017). *Hurricane Irma cut power to nearly two-thirds of Florida's electricity customers - Today in Energy*.

Washington Post (2017). *What Irma's wind and water did to Florida*.

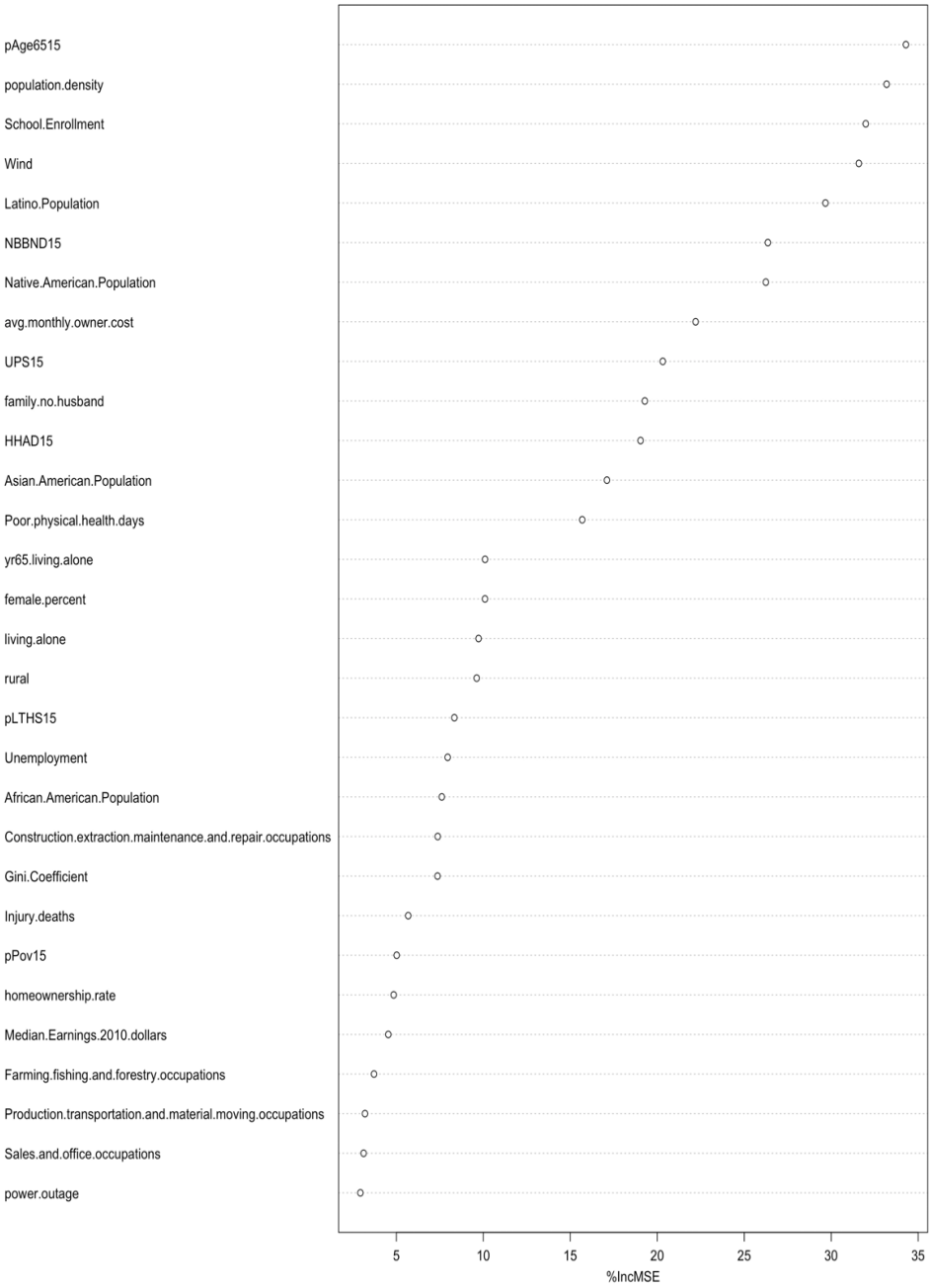


Figure 2. %IncMSE in Random Forest Sensitivity Analysis: $\frac{Tweets}{Claims}$

Towards Automated Individual Communication for Coordination of Spontaneous Volunteers

Sophie Gerstmann
Chair of Information Management
Martin Luther University, Halle, Germany
sophie.gerstmann@student.uni-halle.de

Hans Betke
Chair of Information Management
Martin Luther University, Halle, Germany
hans.betke@wiwi.uni-halle.de

Stefan Sackmann
Chair of Information Management
Martin Luther University, Halle, Germany
stefan.sackmann@wiwi.uni-halle.de

ABSTRACT

In recent years, spontaneous volunteers often turned out to be a critical factor to overcome disaster situations and avoid further damages to life and assets. These Volunteers coordinate their activities using social media and mobile devices but are not integrated in usual command and control structures of disaster responders. The lack of professional disaster response knowledge leads to a waste of potential workforce or even dangerous situations for the volunteers. In this paper, a novel approach for a centralized coordination of spontaneous volunteers through disaster response professionals while using popular communication channels esp. messaging services (e.g. Facebook Messenger, WhatsApp) is presented. The architecture of a volunteer coordination system focusing on automated multi-channel communication is shown and the possibilities of a universal chatbot for individual assignment and scheduling of volunteers are discussed. The paper also provides first insights in a demonstrator system as a practical solution.

Keywords

Spontaneous volunteers, chatbot, social media, system architecture

INTRODUCTION

The growing number of disaster incidents in the recent past represents a new challenge for many societies and reveals new dangers for life and assets (e.g. Munich Re, 2018). Another problematic phenomenon for disaster response is the decreasing number of honorary volunteers in many security authorities and organisations (SAO) (e.g. McLennan et al. 2016). On the other hand, new technologies such as social media and mobile devices allow an even faster and more direct communication from SAOs to the people than ever before. This reveals new possibilities to use the potentials of unaffiliated citizens for provision of workforce and material in critical situations (Sauer, 2014). These spontaneous unaffiliated volunteers (SUV) do already play an important role and were crucial to overcome disasters, for example the Middle European Flood in 2013 (Thieken et al., 2016).

However, it is currently challenging for SAOs to access this new potential due to differences in the organizational structure and especially a missing direct, individual communication channel (Whittaker et al., 2015). Whereas SUVs use popular tools such as Facebook or Twitter to organise themselves, official responders have separate command and control systems and communication channels. The usual communication between these two groups is mostly conducted with mass media calls from officials or deployment of emergency call centres. Although sharing of information between civilians and SAOs in general makes great progress with tools such as Ushahidi or several warning apps, a direct communication for a goal oriented coordination and exploitation of the

spontaneous willingness to help in a disaster situation has not yet been established.

In recent disaster events, the self-organisation of SUVs often led to situations where official responders were overwhelmed by spontaneous converging volunteers. Coordination of these unexpected large crowds of people can be very challenging especially during critical response activities or under dangerous circumstances. Deficits in volunteer coordination can not only lead to a waste of workforce but also decrease motivation to offer help in future events or even cause improper and counterproductive actions of unguided, enthusiastic non-professionals, necessitating further response efforts or even cause new damages (Barsky et al., 2007).

To overcome this situation approaches such as Betke (2018) propose so called volunteer coordination systems (VCS) that provide a direct communication between official responders and SUVs for a goal-oriented management of volunteering offers and demands. A crucial feature of this kind of systems is the possibility to take the individual circumstances of each volunteer into account. This refers to the individual communication behaviour by supporting a variety of popular communication systems as well as to the individual volunteering offer in terms of e.g. time and capabilities. Since the necessary information would exceed the capabilities of official responders, we suggest a (semi-) automated solution.

In this paper, we take up the idea of the VCS and try to answer the question: how can chatbots be used to improve the coordination of spontaneous unaffiliated volunteers? Therefore, we discuss the idea and architecture of an automated multi-channel chatbot as communication interface for SUVs and VCS. This work is part of the research project KUBAS in which different aspects of a VCS are investigated to develop a suitable holistic system. The project follows the design science research process of Peffers et al. (2006) whereas papers such as Betke (2018) address the first phases, this paper addresses the design and development phase (phase 3). In the second chapter, we derive general requirements for a suitable coordination interface for SUVs in a volunteer coordination system. Then we take a short look at chatbots in general and their current application in disaster response in search of a possible existing solution. Chapter three comprises the discussion of new volunteer chatbot architecture with respect to the former derived requirements followed by an insight in an early demonstrator. The paper closes with a summary and outlook for the next project steps.

REQUIREMENTS FOR INDIVDUAL VOLUNTEER COORDINATION

To design a suitable communication interface for SUVs we first need to define the specific requirements. Betke (2018) presented user stories of volunteers and official responders to describe the functional demands of both user groups of a VCS. However, we excluded official responders' side since they did not address the volunteer communication. Instead, we take a closer look on the volunteer user stories to derive the specific requirements for a volunteer-coordination-interface (VCI) between SUVs and SAOs respectively the intermediate VCS. As a typical human-computer-interface, the VCI is a frontend module with the purpose to present, receive and transfer information.

Besides the functional requirements discussed below there are two universal demands on the VCI, whereby the first one is to include as many popular communication systems as possible to reach the maximum number of possible volunteers and the second is an automation of the communication as far as possible. The following table (Table 1) comprises the original user stories and a short explanation of the derivation of each functional requirement (R1-R13). The requirement have been discussed in a workshop with a complete crisis committee staff consisting of six staff members.

Table 1. Volunteer Communication Requirements

	User Story	VCI Requirement
R1	*As a volunteer, I want to be informed about relevant help requests so that I do not have to search for them.*	This user story implicates the need for an automated and individual notification about a relevant mission for the volunteer.
R2	*As a volunteer, I want to get detailed information about help request so that I can make a decision to help.*	The information about help requests must be presented in an appropriate way. The VCI needs access to all data important for the decision making of the volunteer. For instance, these may include mission site, period and type of mission.
R3	*As a volunteer, I want to see my volunteer mission details at any time so that I do not lose any information.*	Information received via the VCI needs to be persistent. It must be accessible and provided at any time so that there are no interruptions in the information flow.
R4	*As a volunteer, I want to provide sufficient information about my*	The VCI must record and retrieve completely and properly all the input data of the volunteer. A processing of different data

	volunteering offer so that I can get the best help requests.	types must be possible.
R5	*As a volunteer, I want to group with my friends so that we can work at the same sites.*	An opportunity to find and interact with friends must be given by the VCI. This can be realized by either using information from existing networks (such as Facebook or WhatsApp) or an underlying VCS. The feasibility and implementation of this requirement depends on the specific data protection laws of each country in which the system is used.
R6	*As a volunteer, I want to change my volunteer offers so that it matches my current circumstances.*	The VCI must provide a function to re-query specific data sets at any time and induce the overwriting process of obsolete data in underlying coordination system. This requirement aims at repeatability of R4. The processing and replacement of data however is a not a feature of the VCI but of the underlying VCS.
R7	*As a volunteer, I want to get information if my volunteering offer was recognized to be sure it will be taken into account.*	The VCI shall give a confirmation to the volunteer once his data was successfully send to the VCS.
R8	*As a volunteer, I want to be able to get offers from more than one request so that I can help at different sites.*	The VCI must be able to present information of a number of requests or accepted missions of a volunteer. This requirement refers to R2 and R3 and implies some kind of navigation through the available information. However, the background processing of data and matching of suitable requests /missions is not part of the VCI.
R9	*As a volunteer, I want to use mobile devices so that I am not bound to a single location.*	The VCI must be designed for deployment on mobile devices of as many different types as possible.
R10	*As a volunteer, I want to use different devices so that I can be sure that I get help request information.*	For the communication between volunteer and the coordination system a multitude of devices (e.g. smartphone, mobile phone, computer) and channels must be addressed. A great variety of devices and channels allows a great participation of potential volunteers. This also concerns universal design aspects as people can communicate and offer help according to their abilities.
R11	*As a volunteer, I want to get information about disaster incidents in my home area so that I can prepare myself.*	Besides features regarding the communication regarding volunteering, the VCI must also serve for information purposes, for instance to inform about critical incidents at the volunteer´s location.
R12	*As a volunteer, I want to share on-site information with disaster authorities so that I can report potentially dangerous incidents.*	The VCI must allow submission of disaster response relevant information. The transfer and presentation of information to disaster authorities is realised by VCS. In connection with a variety of supported communication channels, this requirement may also serve as a connection between physical and digital volunteers whereby the former send information from their mission site for analysis by the latter.
R13	*As a volunteer, I want to get information about the traveling options so that I arrive on site as fast as possible.*	The VCI must provide some kind of routing feature to the volunteer, e.g. via external applications and display this information appropriately.

The derived requirements may not be exhaustive but constitute a good basis with cornerstones for the development of a useful communication interface for SUVs. As stated in Betke (2018), most of the presented requirements, such as local independence or a persistent information flow, can be realised by a mobile app. However, the sole application of a mobile app restricts the communication with volunteers in many ways. On the one hand, the

potential user group is limited to owners of devices such as smartphones and tablets, excluding people with other devices such as simple cell phones or landline telephones. On the other hand, a stable broadband connection or wireless network must be accessible to guarantee the functioning of the app. Since this cannot be guaranteed in every disaster situation the usage of alternative communication channels should be taken into account. Apart from that, it is very important to include popular communication platforms especially social media, which recently became crucial for self-organisation of volunteers (Kaufhold and Reuter, 2016). To reach as many volunteers as possible and to utilise the full potential volunteer offers, we propose the implementation of a universal chatbot as VCI and discuss this in the following.

CHATBOTS IN DISASTER RESPONSE

Chatbots, also often referred to as conversational agents or virtual assistants, are software agents that enable an intelligent and individualised text-based communication between human and computer-based systems. As an extension to simple text-based dialogue systems, chatbots are able to understand, process and respond in natural language. Therefore, they are able to store the user input and respond to the request in the current context (Androutsopoulou et al., 2018; Ciechanowski et al., 2019). Present chatbot frameworks and platforms often offer a multi-channel integration (e.g. SMS, social messenger services), which allows the developer to design a single chatbot and let it interact on various channels. A further benefit of chatbots based on these frameworks is the lower effort for maintenance and adjustment. Another general advantage of chatbots is the high level of user-friendliness. Whereas app-users have to download and install the volunteer app to register for missions, chatbot-users can use a pre-installed messenger service, for example Facebook or WhatsApp, or simply communicate with the chatbot via SMS. Furthermore, the menu prompting of an app sometimes can be confusing. A chatbot however, leads the user through a dialogue requiring less technical comprehension and so also opens the system for further user groups, for example illiterate persons via text-to-speech technology. Chatbots can instantly respond if the user's entry was incorrect or unclear. Thus, users can always be aware that their input has been accepted. In contrast to an app, the communication between user and system can be designed personally and human-like. Due to the human-like behaviour, possible fears of using computers can be reduced (Zamora, 2017; Muir, 1987). The direct interaction allows monitoring of the users´ emotion, e.g. by analysing the choice of words to get insight into their satisfaction with the chatbot. Several studies have been conducted to analyse the user's perception of a chatbot. According to Zamora (2017), users consider the application of their own natural language and short interaction times as further advantages of chatbot communication. To what extent a chatbot is perceived by users as beneficial depends on its ability to lead human-like conversations and process and respond in natural language (Shawar and Atwell, 2007; Wuenderlich and Paluch, 2017).

Because of the previously mentioned benefits, chatbots take over the communication with customers in a rising number of business applications. In banking, finance and insurance sectors they take over tasks such as checking the balance or block the credit card in order to prevent a fraudulent use (Dole et al., 2015; Eling and Lehmann, 2018; Koetter et al., 2018). In the tourism sector chatbots inform about the cheapest flight available or book a table in a restaurant (Ivanov and Webster, 2017; Nica et al., 2018). They assist customers in finding the right product on e-commerce websites or answer product related questions (Johannsen et al., 2018; Cui et al., 2017; Thomas, 2016). In social networks social bots automatically communicate with users and are criticised for manipulating their opinion on political issues (Ferrara et al., 2016; Wagner et al., 2012).

In order to provide an overview on the current state of research devoted to the use of chatbots in disaster management, we conducted a literature analysis. For this purpose, the several scientific online databases, of ScienceDirect, ISCRAM and AIS as well as Google Scholar have been searched for the keywords "chatbot", "bot", "conversational agent" and "virtual assistant" in combination with "disaster", "crisis", "catastrophe" and "volunteer". The identified relevant literature gives evidence that chatbots have the potential to improve the communication between public authorities and the civilian population. They are especially qualified to provide clarification on complex issues and for information purposes in civil protection. (Androutsopoulou et al., 2018). Currently, chatbots are mainly used for decision support and information retrieval in the phases of disaster preparedness and response. Thus, Augello et al. (2016) propose a model where a chatbot is used to warn decision-makers and civilian population of impending environmental catastrophes and support them in decision-making. For this purpose, the chatbot collects information from various sources. Sensors at measuring stations provide data to predict the future development and describe the current status of a disaster. In addition, the chatbot uses input information about users, for example their current location. This information is combined to provide an individual situation aware risk assessment of the user situation and offers advisory function. Sermet and Demir (2018) follow a similar approach. They developed an intelligent system using an ontology based knowledge engine to improve societal preparedness for flooding with help of voice recognition, artificial intelligence and natural language processing. The chatbot uses information from an official flood information system

Besides these scientific approaches, chatbots are already used in practice. For instance, in the U.S. the Richter

chatbot assists users in preparation for an impending earthquake or tsunami (BotList, 2018). It provides educational videos about how to behave in a critical incident, provides the users with documents to create their personal emergency plan and informs about the nearest public shelter and emergency services. In Japan, Bebot, a multi-language chatbot, sends alerts and information about nearby evacuation areas to visitors (Japan Today, 2018).

The chatbots presented already meet some of the requirements from chapter 2. For example, the chatbot of Sermet and Demir is able to process natural language, which ensures that all user input is retrieved properly (R4). Almost any of the presented chatbots is able to inform the user on disaster incidents, which meets requirement R11. Nonetheless, the main intention of chatbots presently used in disaster management is merely information retrieval for improving personal safety. Therefore, existing approaches have a different target audience and none of them takes coordination of volunteers into account. Since the literature analysis did not reveal a suitable chatbot solution as communication interface for SUVs, we will discuss the design of an appropriate software artefact serving this purpose in the following chapter.

VOLUNTEER COORDINATION SYSTEM WITH MULTI-CHANNEL COMMUNICATION

As stated before, the purpose of the chatbot proposed in this paper is to serve as a communication interface between SUVs and a VCS, which processes data from volunteers as well as SAOs to support an optimal usage of the volunteering potential. We therefore designed the chatbot as one module of a holistic VCS. The respective VCS architecture extract depicted in Figure 1, consists of a communication subsystem comprising the chatbot, a management engine and interfaces for communication devices of the volunteers on the one hand and official on-site responders on the other. On site responders or crisis committees, send their requests to the coordination system, which are then handled by the management engine. SUVs send their offers through the channel of their choice, which are attached to the chatbot via web interface. The chatbot takes over the communication with the volunteer. Based on natural language processing (NLP), the chatbot detects the user intents and induces the management engine to process their request. Hereinafter the single modules of our proposed architecture are described.

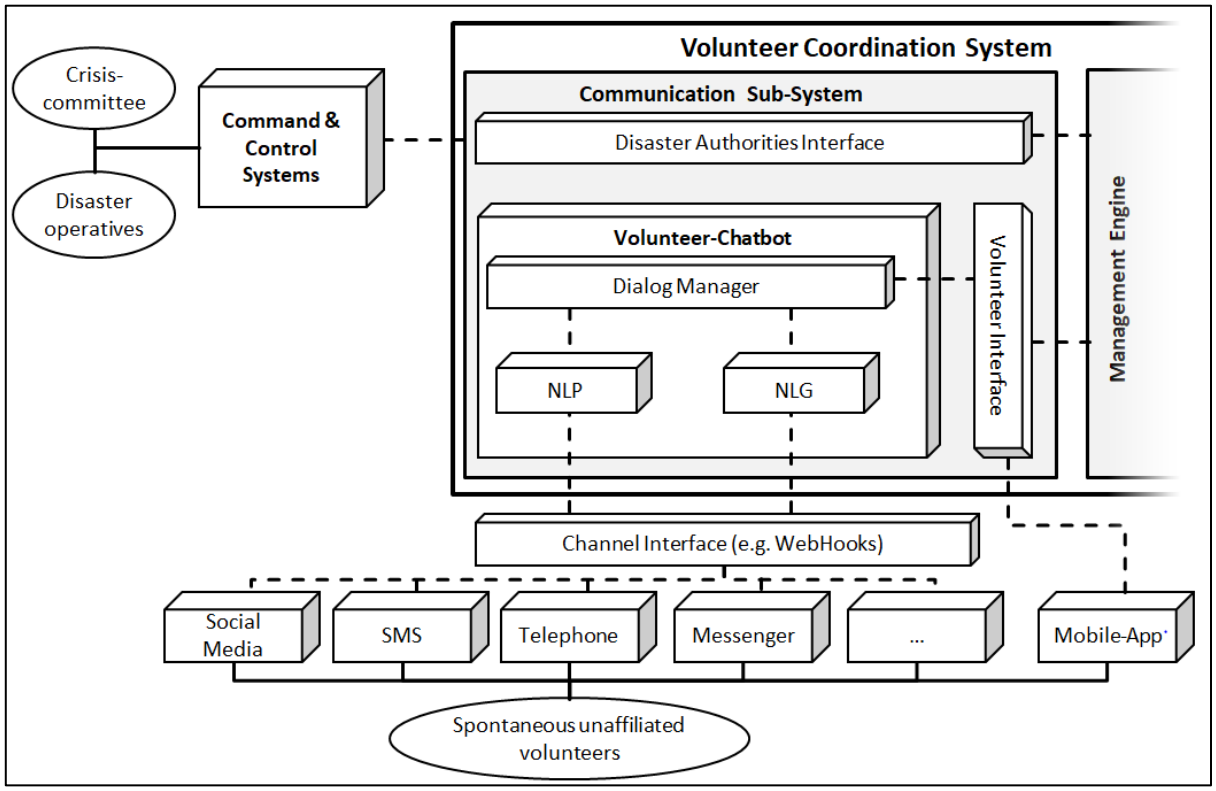


Figure 1. Volunteer Chatbot Architecture

The management engine in the proposed architecture consists of a workflow engine, which manages all in - and outgoing information as well as the interaction of all further system components. It comprises the database where all information about volunteer offers, help requests and volunteer user data is stored (R6). The engine monitors the individual status of each volunteer (e.g. offers, mission status, location, communication channel). Another major component connected to the management engine but not displayed in figure 1 is the decision support module

whose task is to constantly analyse the situation on volunteer offers and help requests to determine matches and provide information about which SUV should be alarmed for open help requests. For a detailed description of the concrete architecture of the coordination system and its modules see Betke (2018).

SUVs communicate their information, for instance registration information, volunteer offers etc. through the chatbot. The chatbot can be called via multiple channels, for instance SMS, Skype or messenger services such as Facebook messenger or WhatsApp (R9, R10). In our proposed architecture these channels are connected to the chatbot via webhooks. If the user's input is matched with a defined event, a callback function will be evoked and a HTTP – POST is sent to the web service, which returns the requested result (R3). To match a request or offer to the correspondent user, the assignment of a specific user id is required (R1). The user id can be extracted from the channel that is used by the user, e.g. account number of social networks, mobile number of messenger services or SMS or is generated and validated by the VCS.

To process user inputs and manage the dialogue between user and system, two solutions exist. The first is to use a simple, rule-based dialog system. To respond to the user input, these dialog systems refer back to pre-defined question-answer patterns. These patterns can be created by using AIML (Artificial Intelligence Markup Language), a derivative of XML. AIML patterns are grouped in intentional categories and contain templates with pre-defined answers. User input is matched against each pattern. Because of that, the chatbot is inflexible when it receives input, which has not been defined in a pattern. A chatbot using AIML is stateless and will not be able to store the conversation state and therefore is not aware of changing context. It can be assumed that volunteers would be unsatisfied, if the chatbot fails to handle their request properly. We therefore suggest the application of artificial intelligence instead of pattern oriented chatbots. Based on machine learning, these chatbots are self-learning and able to answer unexpected questions. In our proposed architecture, the dialog system consists of a natural language understanding (NLU) component, the dialog manager and a natural language generator (NLG). The NLU component is responsible for analysing the user input and triggering an action according to the user intent. For this purpose, intents have to be defined by the developer and the NLP component has to be trained on a variety of possible user input (R4) and chatbot output sentences. For example, to register for a mission a volunteer could ask "How can I register for a mission?" or simply "I want to help". Although the queries have a completely different syntax, both have the same intent (register for a mission). Based on machine learning the NLP component checks the query against every defined intent and matches it to the most suitable. To extract the specific parameters of an intent, for instance preferred date and time of a mission, entities need to be defined. Entities specify one or many actions of a single intent and represent a class of objects with values representing possible objects of this class. Another opportunity to train the chatbot for intent detection is the use of ontologies, which connect intents, phrases, nouns, adjectives and the relationships among them to a specific domain. For instance, if the user asks "How can I register for a mission?" the chatbot will parse the query and locate the register entity in the ontology. If the register entity is related to the time and date entity, the chatbot will ask the user to input their name to register for a mission.

After understanding the user intent, the chatbot needs to respond correctly and with the data that have been requested by the user. This is managed by the dialog manager. For this purpose, the dialog manager needs to maintain the context of the information and control the dialog or rather information flow. To execute the registration process, the chatbot needs to know all the relevant information, for instance user name, preferred mission site etc. If the input data of the user is unspecific and further information is needed, the chatbot needs to realize the missing data and request the user to fill in these slots. To avoid user input that cannot be processed by the chatbot or potentially leads to a misunderstanding and perhaps to cancellation of the registration process, we suggest designing a dialog, which is strongly guided by the chatbot itself. This can be done by providing the user with a set of predefined options. Thus, the user is led through the conversation by the chatbot and is always aware of what they say next. If there is nevertheless invalid user input, the chatbot will send a default message, implying that the input could not have been processed (R7). In order to fulfil the registration process, the dialog manager needs to pass the relevant data to the management engine. For this purpose, depending on the intents and entities extracted by the NLG component, a specific JSON code is generated and transferred to the management engine that can be called via REST API. To find an appropriate mission, the dialog manager sends the relevant data to the management engine and posts a request on available missions. The management engine will check the received data with the data sent by official responders and send these data back to the dialog manager (R8). Natural Language Generation is applied on constructing the answer containing the requested information on proposed missions. For this, the dialog manager uses templates and replaces the slots with the data retrieved from the management engine (R1, R2). If the user accepts the mission, this information needs to be stored in the database of the management engine and the dialog manager sends a confirmation to the user (R7). Besides registering and assigning for missions, users also required the opportunity to send on-site information to disaster authorities (R12). To realise this requirement, the chatbot needs to retrieve the needed information from the user by working through a series of questions determining the dimensions of the incident (e.g. What happened? Who was involved? When did it happen?). Again, the management engine manages the passing of this information to disaster authorities.

Furthermore, it was required for the communication system to have access to external applications. To provide general information on critical incidents at the SUV'S location, the communication system can be connected to a public warning system or retrieve information direct from official responders via the VCS (R11). The data is processed and preselected by the management engine, which triggers the chatbot to start a warning dialogue. To group with friends (R5), access to social networks is required, whereby the interface of social networks usually can be called via webhooks. Alternatively, the user can group with friends within the communication system by providing identifying information such as mobile number, sur- and last name. For on-site routing (R13), access to travel apps is needed, for instance map services or train connections. For this purpose, the chatbot needs a template, which can integrate and display the routing graphically or work as announcer for a navigation system.

SIMPLE CHATBOT DEMONSTRATOR

So far, we have implemented a first simple prototype chatbot on Facebook messenger via Chatfuel. Chatfuel is a bot platform for creating simple dialogs on Facebook messenger. We decided to use the Facebook messenger for a first exemplary implementation since it offers a mature API, large user base and is an important platform for volunteers. This chatbot is used as demonstrator to evaluate the technical feasibility and give a first impression on the user acceptance for this communication method.

The chatbot's ability to respond to user input depends on the amount of training examples connected to the specific intent. We generated training examples by searching a thesaurus for synonyms, for example "help", "register" and "volunteering". The training examples were supplemented in the course of time with the growing experience that we made with users testing the chatbot. To minimalize the risk of wrong user input, we designed the chatbot to suggest a set of options from which users can choose. In addition, it is possible to interact with the chatbot by putting own questions. Every dialog starts with the chatbot introducing itself and offering the user to either register for a mission, to get information on the VCS-system (called KUBAS in our example) or the possibilities of voluntary work in general. If the user wants to register for a mission, the chatbot then asks about their preferred work. If there is a suitable mission for the volunteer, the user is then asked to confirm their offer and will be sent a confirmation (Figure 2).

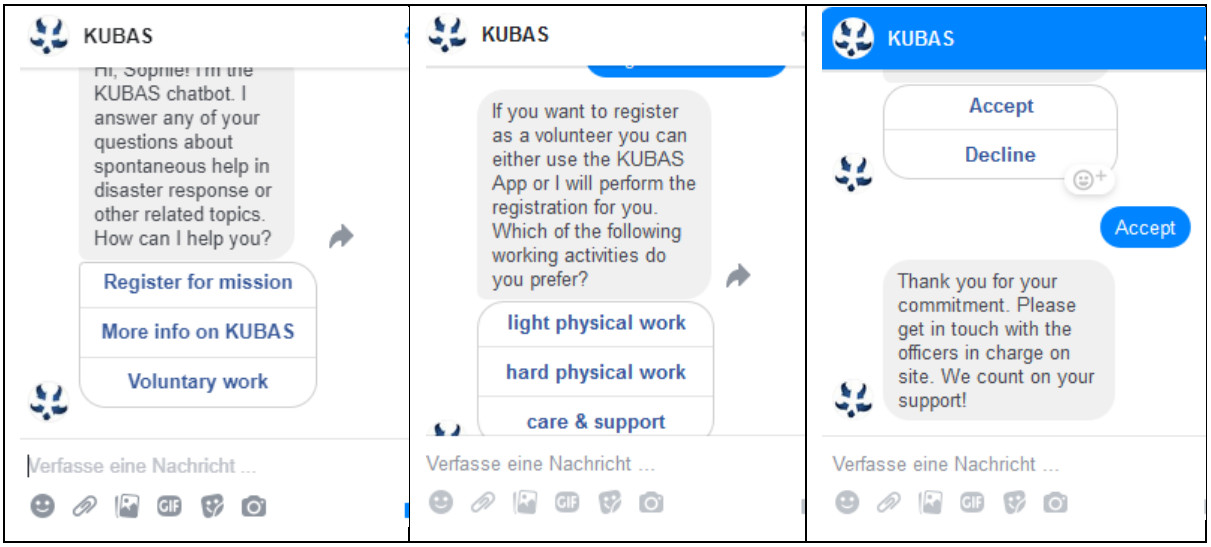


Figure 2. Chatbot Functions (Welcome message, Offering working activities, Confirmation of mission)

On an invalid input, the chatbot will send a default answer, informing that the user input has not been understood and referring to our KUBAS website for further information and assistance.

Our chatbot demonstrator has been presented to a specialist audience of disaster authorities and organisations at several workshops and got thoroughly positive feedback. Testers especially highlighted the integration in existing social networks, uncomplicated usage via natural language, direct feedback and reduced workload though automatisation. They mentioned a great potential for the application of chatbots in disaster response and volunteer coordination. However, at the present time the chatbot is not able to connect with the coordination platform, and therefore, volunteers are not able to register for a mission. In addition, we learned from user testing, that a more human-like conversation is desired. For this purpose, more training examples need to be provided. As the use of emoticons, such as the like-button on Facebook is very common, especially on messenger services, the processing of emoticons needs further exploration. Requirements such as grouping with friends or integrating information from external applications have also not been implemented yet. Our next steps will be to switch to another platform

that will allow multi-channel integration, such as Dialogflow, and to further develop the dialog and connect the chatbot to a VCS platform.

CONCLUSION

To reach a wide range of volunteers and to increase resilience by using a large variety of communication channels, we proposed an architecture that comprises a chatbot to handle the communication flow between VCS and SUVs. We used user stories, that have been developed in earlier work (see Betke 2018), to retrieve requirements for a communication system. We consider chatbots to be a suitable tool to meet these requirements, since just one chatbot is able to operate on many different channels, such as SMS and messenger services. Furthermore, chatbots are considered to be user-friendly and have the potential to simplify the registration process for the volunteer. So far, a simple chatbot has been implemented in our KUBAS Facebook messenger.

However, this chatbot does not meet all the requirements set out in this paper, as it is only able to conduct a basic conversation with the user, but not connected to a VCS. Future work focuses on further development of the demonstrator chatbot including the necessary VCS integration, multi-channel support and redefinition of the dialog modelling based on natural language processing. We plan to evaluate the usability of the chatbot in a large-scale exercise with a large number of SUVs and disaster authorities. Evaluation will include a comparison of SUV coordination with volunteer coordination app, chatbot and social media.

ACKNOWLEDGMENTS

The paper is part of the KUBAS project (www.kubas.uni-halle.de) conducted by Martin-Luther University Halle-Wittenberg, University of Regensburg, City of Halle (Saale), ESRI Germany and sponsored by the German Federal Ministry of Education and Research.

REFERENCES

Androutsopoulou, A., Karacapilidis, N., Loukis, E. and Charalabidis, Y. (2018) Transforming the communication between citizens and government through AI-guided chatbots, *Government Information Quarterly* [online] https://doi.org/10.1016/j.giq.2018.10.001.

Augello, A., Maniscalco, U., Pilato, G. and Vella, F. (2016) Disaster Prevention Virtual Advisors Through Soft Sensor Paradigm, in Pietro, G.D. et al. (Eds.), *Intelligent Interactive Multimedia Systems and Services 2016*, Springer, New York, 619–627.

Barsky, L. E., Trainor, J. E., Torres, M. R. and Aguirre, B. (2007) Managing volunteers: FEMA's Urban Search and Rescue programme and interactions with unaffiliated responders in disaster response, *Disasters*, 31, 4, 495-507.

Betke, H. (2018) A Volunteer Coordination System Approach for Crisis Committees, *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management*, Rochester, NY.

BotList (2018) Meet Richter - Earthquake preparation made simpler. [online] https://botlist.co/bots/meet-richter.

Ciechanowski, L., Przegalinska, A., Magnuski, M. and Gloor, P. (2019) In the shades of the uncanny valley: An experimental study of human–chatbot interaction, *Future Generation Computer Systems*, 92, 539–548.

Cui, L., Huang, S., Wei, F., Tan, C., Duan, C. and Zhou, M. (2017) SuperAgent: A Customer Service Chatbot for E-commerce Websites, *Proceedings of Association for Computational Linguistics 2017*, Vancouver, CA.

Dole, A., Sansare, H., Harekar, R. and Athalye, S. (2015) Intelligent Chat Bot for Banking System, *International Journal of Application or Innovation in Engineering & Management*, 4, 5, 49–51.

Eling, M. and Lehmann, M. (2018) The Impact of Digitalization on the Insurance Value Chain and the Insurability of Risks, *The Geneva Papers on Risk and Insurance - Issues and Practice*, 43, 3, 359-396.

Ferrara, E., Varol, O., Davis, C., Menczer, F. and Flammini, A. (2016) The rise of social bots, *Communications of the ACM*, 59, 7, 96-104.

Ivanov, S.H. and Webster, C. (2017) Adoption of Robots, Artificial Intelligence and Service Automation by Travel, Tourism and Hospitality Companies – A Cost-Benefit Analysis, in Marinov, V., Vodenska, M., Assenova, M. & Dogramadjieva E. (Eds), *Traditions and Innovations in Contemporary Tourism,* Cambridge Scholars Publishing, Cambridge, 190-203.

Japan Today (2018) AI chatbot offers new natural disaster support feature. https://japantoday.com/category/features/new-products/ai-chatbot-offers-new-natural-disaster-suort-feature.

Johannsen, F., Leist, S., Konadl, D. and Basche, M. (2018) Comparison of commercial chatbot solutions for supporting customer interaction, *26th European Conference on Information Systems*, Portsmouth,UK.

Kaufhold, M. A. and Reuter, C. (2016) The self-organization of digital volunteers across social media: The case of the 2013 European floods in Germany, *Journal of Homeland Security and Emergency Management*, 13, 1, 137-166.

Koetter, F., Blohm, M., Kochanowski, M., Goetzer, J., Graziotin, D. and Wagner, S. (2018) Motivations, Classification and Model Trial of Conversational Agents for Insurance Companies, *11th International Conference on Agents and Artificial Intelligence 2019*, Prague, CR.

McLennan, B., Whittaker, J. and Handmer, J. (2016) The changing landscape of disaster volunteering: opportunities, responses and gaps in Australia, *Natural Hazards*, 84, 3, 2031-2048.

Muir, B.M. (1987) Trust between humans and machines, and the design of decision aids, *International Journal of Man-Machine Studies*, 27, 5, 527-539.

Munich RE (2018) Number of relevant natural loss events worldwide 1980-2017. [online] https://natcatservice.munichre.com/events/1?filter=eyJ5ZWFyRnJvbSI6MTk4MCwieWVhclRvIjoyMDE3fQ%3D%3D&type=1.

Nica, I., Tazl, O.A. and Wotawa, F. (2018) Chatbot-based Tourist Recommendations Using Model-based Reasoning, *20th International Workshop on Configuration*, Graz, A.

Peffers, K., Tuunanen, T., Gengler, C. E., Rossi, M., Hui, W., Virtanen, V. and Bragge, J. (2006) The design science research process: a model for producing and presenting information systems research*, Proceedings of the first international DESRIST 2006*, 83-106.

Sauer, L. M., Catlett, C., Tosatto, R. and Kirsch, T. D. (2014) The utility of and risks associated with the use of spontaneous volunteers in disaster response: a survey, *Disaster medicine and public health preparedness*, 8, 1, 65-69.

Sermet, Y. and Demir, I. (2018) An intelligent system on knowledge generation and communication about flooding, *Environmental Modelling & Software*, 108, 51–60.

Shawar, B.A. and Atwell, E. (2007) Chatbots: are they really useful?, *LDV Forum: Journal for Language Technology and Computational Linguistics*, 22, 29-49.

Thieken, A.H., Kienzler, S., Kreibich, H., Kuhlicke, C., Kunz, M., Mühr, B., Müller, M., Otto, A., Petrow, T., Pisi, S. and Schröter, K. (2016) Review of the flood risk management system in Germany after the major flood in 2013, *Ecology and society*, 21, 2.

Thomas, N.T. (2016) An e-business chatbot using AIML and LSA, *International Conference on Advances in Computing, Communications and Informatics*, Piscataway, NJ.

Wagner, C., Mitter, S., Körner, C. and Strohmaier, M. (2012) When social bots attack: Modeling susceptibility of users in online social networks, *Proceedings of the WWW'12 Workshop on 'Making Sense of Microposts'*, Lyon, FR.

Whittaker, J., McLennan, B. and Handmer, J. (2015) A review of informal volunteerism in emergencies and disasters: Definition, opportunities and challenges, *International journal of disaster risk reduction*, 13, pp.358-368.

Wuenderlich, N.V. and Paluch, S. (2017) A Nice and Friendly Chat with a Bot: User Perceptions of AI-Based Service Agents, *International Conference on Information Systems 2017*, Seoul, ROK.

Zamora, J. (2017) I'm Sorry, Dave, I'm Afraid I Can't Do That, *The 5th International Conference on Human-Agent Interaction*, Bielefeld, DE.

Evaluation of Digital Volunteers using a Design Approach: Preferences and Motivations in Disaster Response

Gabriela Barrera*
Department of Mechanical Engineering
Massachusetts Institute of Technology,
Cambridge, MA 02139 †
gcb@mit.edu

Maria Yang
Department of Mechanical Engineering
Massachusetts Institute of Technology,
Cambridge, MA 02139 ‡
mcyang@mit.edu

ABSTRACT

With the growth of social media and crowdsourcing in disaster response, further research is needed on the motivations and contributions of digital volunteers. This study applies a user-centered design approach to understanding how we might make better tools to support digital volunteers. This user-centered design approach involves stated preference elicitation methods through an online survey to understand what digital volunteers want in such tools. Through choice-based conjoint analysis, we contribute to mixed-methods research to gain additional insight into motivations and user preferences for a set of design features that might be incorporated into an online tool specifically for digital volunteers. Initial results show preferences for measures of success that were not monetary, which aligned with directly stated motivations for volunteering. Our findings corroborate with previous research in that feedback to volunteers is very important, as well as being able to measure the impact of their work.

Keywords

Disaster Response, Crowd-sourcing, Digital Volunteer, Social Media, User Design

INTRODUCTION

Emergency and disaster management has been transformed by mobile technologies and social media. Social media is particularly useful for emergency responders to communicate and gather information, meet and manage citizen expectations, increase situational awareness, and leverage citizens as force multipliers (Williams and Phillips, 2014). Previous uses of social media by the affected community and through global digital volunteers through Open Street Maps (OSM) and Twitter have largely been effective (Bjerge et al., 2016). Briony (2018) has made a number of observations about the value of social media for disaster response, particularly in the Caribbean. First, social media has shown potential as an additional channel for disaster response functions and services: Facebook offers preparedness information, WhatsApp has been relied upon for coordination and planning, and Twitter has been used for real-time weather updates to an extent. Second, social media is particularly useful as they are free to access with an internet connection, require little authentication to use, and are available in real-time. Third, the increasing use of social media, especially in small island developing states (SIDS), is important due to islands in the Caribbean featuring compressed spatial scales (local level is similar to national level). Further, the expanded use of social media has led to the growth of resilience and preparedness information online. Finally, as a tool to facilitate hurricane resilience, social media is a priority for SIDS to encourage and enable community engagement (Briony, 2018).

Despite the usefulness of social media, a main challenge is lack of relevancy and clarity of information provided due to the massive volume of available information after events and the fact that much of it can be considered noise (Cobb et al., 2014). There are often tradeoffs between gathering enough information to assess disasters and reducing

*corresponding author
†http://meche.mit.edu/ and http://ideation.mit.edu/
‡http://meche.mit.edu/ and http://ideation.mit.edu/

information and channels to be able to respond quickly (Leidner et al., 2009; Zhang et al., 2002). Many involved in disaster management are not always able to distinguish between channels, leading to uncertainty and loss of time (Bjerge et al., 2016). This may be partly due to lack of standardization as there is no customary approach across all actors to evaluate information (Commonwealth Telecommunications Organisation (CTO), 2006; Leidner et al., 2009; Williams and Phillips, 2014; Meissner et al., 2002). There has been growing interest and research on how to leverage the deluge of social media data for disaster management, including online platforms and tools that focus on crowdsourced data (Poblet et al., 2018).

Crowdsourced efforts can be critically important in disaster response, especially as they can be a way to handle big data and reduce the noise in information from social media. Crowd participation can better handle large tasks and data analysis needs through bringing digital volunteers together (Briony, 2018). Digital volunteers are those remotely located to a disaster that contribute either as individuals or within networks or organizations to the response effort (Poblet et al., 2018). They are unaffected individuals using social media and other online tools to assist in disaster response efforts by taking on tasks such as information processing through filtering and mapping crisis-related social media data (Cobb et al., 2014). Social media has become the main tool for digital volunteers, and the use of crowdsourcing platforms has improved volunteers' contributions to disaster management. A main task that digital volunteers conduct is media monitoring, including social media posts, to find new, relevant information and curating it into usable resources (Cobb et al., 2014). Given the value of social media's role in facilitating the efforts of digital volunteers, it is clear that there are substantial opportunities for the creation of online tools to better support their efforts. In this paper, we take a human-centered design approach to these tools that begins by understanding the needs and motivations of digital volunteers.

This study explores two main research questions on digital volunteers in disaster response: what features do they prefer in a digital volunteer platform and what are their main motivations to volunteer in disaster response? We conducted a multi-faceted survey with digital volunteers and potential digital volunteers to (1) assess their preferences for a digital volunteer platform, (2) assess their stated motivations for digitally volunteering in disaster response, and (3) gain insights into the design features of tools for crowdsourcing. Through this study, we hope to identify opportunities to improve the future design of digital volunteer and crowdsourcing tools for disaster response.

RELATED WORK AND RESEARCH GAP

Digital Volunteer Roles

Digital volunteers have become an established feature of crisis events. The main reasons for this include: (1) their motivation to make citizen-reported information usable and (2) access to online tools that allow them to access this information and coordinate their work (Cobb et al., 2014). Digital volunteer communities are one of four roles that crowds take on in crisis management based on distinct skills and expertise. Liu et al. (2014) identified these four roles as: 1) affected populations, 2) diasporas, 3) social networks, and 4) digital volunteer communities. In these roles, disaster-affected populations provide "local, timely, and direct experiential information", diasporas provide unique "socio-cultural tacit knowledge", social networks provide "varied background with unexpected and possible fortuitous experience', and digital volunteers offer their "capabilities in processing and managing crisis data" (Liu et al., 2014). Further, digital volunteers can take on different organizational forms in disaster response.

Empirical research on recent disaster events shows digital volunteer work can take place in four different organizational forms: established, extending, expanding, and emerging (Cobb et al., 2014). The emerging or 'emergent' category is identified by ordinary and local individual citizens that contribute to emergency response through new and informal groups (Sebastian and Bui, 2009). Emergent organizations of remote actors connected through social media are "now a feature of disaster response milieu," as evident through various examples of emerging organization assistance in the Haiti earthquake, Alabama and Joplin tornadoes in 2011, and Hurricane Sandy in New Jersey (Cobb et al., 2014). The expanding category is identified by having an established structure between events, but increased capacity for response during events by activating part time volunteers and bringing in new ones (Cobb et al., 2014). This category includes ongoing digital volunteer organizations that use online tools to provide remote assistance during disaster events, such as Crisis Commons, CrisisMappers, Standby Task Force, and Humanity Road (Cobb et al., 2014). In various organizational forms, digital volunteers have proven as key actors in a disaster response. We focus on the role of digital volunteers as emergent actors by assessing their motivations and incentives.

Digital Volunteer Motivations

Previous studies have surveyed digital volunteers that processed online and social media streams during crisis events and identified important motivations and incentives. A large number of studies have used Open Street Maps as a case study to determine the engagement and motivations of citizens as volunteers and have found participants

want to share their knowledge, experience community, learn new things and advance their career (Baruch et al., 2016). For other platforms, there can be very different motivations such as the desire to contribute to scientific discovery (Baruch et al., 2016). Santos Rocha et al. (2016) review literature on citizen engagement and identified motivations of digital volunteers including: connection to the area, ideology, personal satisfaction, community, humanitarian values, and desire to apply and improve technical knowledge (Santos Rocha et al., 2016). Other important incentives include: encouraging volunteers by giving feedback, recognition, appreciation and gratitude; cultivating sense of ownership and accountability; generating a feeling of inclusivity based on collaborations; and providing training and capacity-building opportunities for volunteers (Santos Rocha et al., 2016). In regards to the effort input of an individual, this is higher when the individual expects that the contribution will yield results (Santos Rocha et al., 2016). Among these incentives, they can influence volunteer's accuracy and task completion differently. Daniel et al. (2018) review crowdsourcing literature and identify that incentives affect the attractiveness of a task in crowdsourcing (Daniel et al., 2018). Incentives can target the extrinsic (reward-driven) or intrinsic (interest-driven) motivations of workers. Increasing extrinsic motivations leads to faster task completion while increasing intrinsic motivations leads to higher quality (Daniel et al., 2018).

Other studies have found motivations can vary based on previous experiences. Cobb et al. (2014) interviewed those who worked remotely to process social media streams as digital volunteers or as emergency response professionals and found a main reason to become a digital volunteer as believing that social media and non-local responders can have an impact during crises. Other reasons they identified included: gain skills for their career, "give back to society because they want to pay it forward and they were impacted," they have extra time on their hands, and they have a personal connection to the area. Among those who used social media in an official capacity, their motivations were to gauge community opinions and misunderstandings so outgoing messages could be tailored to specific needs and they then connected to people doing digital volunteer work (Cobb et al., 2014). This study also found different motivations for continuing as a digital volunteer, especially considering many interviewees described disaster fatigue can occur after responding to an event since continued participation has a significant cost (Cobb et al., 2014). Motivations for sustained membership included: altruism, making an impact, knowledge of definitive impact, formation of identity as a digital volunteer, connecting their work in the crisis space to their self-identity, the personal relationships that volunteers forge with each other, and gain new skills through digital volunteer work that may benefit them in other areas of their lives or in future disaster (and non-disaster) scenarios (Cobb et al., 2014).

Baruch et al. (2016) examine online crowdsourcing from the perspective of volunteers and the campaign coordinator of Tomnod, an online mapping project owned by Digital Globe that uses crowdsourcing to identify objects and places in satellite images (Baruch et al., 2016). Through online surveys, they found participant demographics influence their motivations including being retired or having a disability or long term health problem leading them to use Tomnod as a "better use" of time or "help in anyway possible" (Baruch et al., 2016). They also found a majority of general motivations aligned with an altruistic theme, including explicitly mentioning that they want to help people in urgent need of assistance (Baruch et al., 2016). Further, some saw contributing to Tomnod as an alternative to charity work and other motivating factors included involvement in a global community, looking for people they know, enjoying the task, and taking part in a fun pastime (Baruch et al., 2016). Altruistic motivations may not be enough, but successful campaigns benefit from volunteers having a sense of satisfaction and achievement on their contributions (Baruch et al., 2016).

For crowdsourcing campaigns in humanitarian applications, there is a need for further research into the motivations and preferences of users (Baruch et al., 2016). The current literature need mixed-methods research to provide an additional depth of insight into digital volunteers (Baruch et al., 2016). In particular, there is further research needed on understanding stakeholder needs and values for the development of a platform used by digital volunteers. This study seeks to contribute to this research in order to improve upon sources of information that help meet the needs of those affected by an emergency or disaster.

Design Features and Conjoint Analysis

Using similar methods to identify motivations for participating as a digital volunteer, previous studies have found specified features of a platform or tool that volunteers would prefer. As found in Baruch et al. (2016) through an online survey, the main features that are preferred in a digital volunteer platform include feedback on quality of contributions, follow-up on how data was used, education or training to improve skills, and engagement with formal organizations like Tomnod. Overall, there was a sentiment of a participant's wish to be more engaged, such as by getting a "certificate of participation or some kind of award" (Baruch et al., 2016). Moreover, a majority of participants referred to wanting some sort of feedback and desire for more information on the campaigns, including how data was used (Baruch et al., 2016). A key feature of various digital volunteer platforms is an 'agree' score that shows how many participants also tagged the same location, but this was viewed negatively by some as it reflected how a volunteer may be wasting their time and they would rather prefer to get feedback on their impact or results (Baruch et al., 2016). Other features that volunteers would like included: greater control over data

(i.e. a more transparent platform), links to Google maps, ability to see what other volunteers are doing, ability to discuss observations with others, and a voting system to choose the campaign that is activated (Baruch et al., 2016). Including this study by Baruch et al. (2016), directly stated questions in surveys and open-ended questions in interviews have largely been used to identify preferences for features of crowdsourcing and digital volunteer platforms for humanitarian and disaster response applications. In other work on individual motivations for digital volunteering and design preferences for crowdsourcing platforms, interviews for persona identification and user trials have been used (Yu et al., 2012b; Ludwig et al., 2017). We seek to apply an approach of user-centered design to understand the preferences and motivations of digital volunteers that has been seldom applied in the field of disaster response.

This study applies a user-centered design approach to understand stakeholder perceptions and motivations for being a digital volunteer in disaster response and to determine important features for a platform for digital volunteers. To obtain meaningful and accurate information from users, conjoint analysis is a widely used and cost-efficient tool to capture preferences for products. Conjoint analysis addresses the additive effect of a set of individual variables on consumer preference (Bao et al., 2014). The type of conjoint analysis used in this study is choice based conjoint, which presents participants with several products with different combinations of attributes and asks them to choose which they prefer (Bao et al., 2014). An example of choice based conjoint analysis is in c, where this method was used to identify preferences for product appearance of solar panels. In the humanitarian and disaster response field, there have been few uses of conjoint analysis including identifying preferences for aid delivery plans (Gralla et al., 2014). Although widely used in market research, conjoint analysis has largely not been used in the field of humanitarian and disaster response nor to capture preferences in crowdsourcing platforms. In this study, the preferences of potential and previous digital volunteers for features of a digital volunteer platform were examined using conjoint analysis.

METHODS

User-based Design and Conjoint Analysis

In this study, choice based conjoint analysis is used as the main preference elicitation method. Conjoint is used widely in marketing for understanding the preferences among attributes in a group of people. In a conjoint analysis, several attributes of a product are chosen, and each attribute can be varied at discrete levels. A controlled set of potential configurations is created by experimental design, and each configuration contains a combination of the attributes (Kuhfeld, 2003). After the set is prepared, users are asked to rate, rank, or choose among the product profiles. Choice based conjoint presents several configurations with different combinations of attributes to users and asks them to choose the one they like the most (Kuhfeld, 2010). With the user ratings, utility models can be built and predictions can be made about users' future preferences. Conjoint analysis is used to address the additive effect of a set of individual variables on consumer preference and is widely used in market research to determine user value of different features that make up a product or service (Green, 1974). As conjoint belongs to the category of stated preference eliciting methods, this was supplemented by directed stating preference methods in the online survey we conducted.

Data Collection

This study's first part includes presenting users with an online survey on a digital volunteer platform with varying features and related questions on experience and potential motivations for volunteering in a disaster response. The details of creation of the survey, administration, and participant demography follow.

Attribute Identification

A literature review was conducted to identify features (or attributes) of crowdsourcing platforms (Poblet et al., 2018; Hossain and Kauranen, 2015), including websites (Yu et al., 2012b), public displays (Ludwig et al., 2017), apps (Gu et al., 2017; Morschheuser et al., 2018; Li and Ulaganathan, 2017), among other systems (Ogie et al., 2019; Yu et al., 2012a), as well as to identify motivating factors for digital volunteers (Cobb et al., 2014; Daniel et al., 2018; Baruch et al., 2016; Spatharioti and Cooper, 2017; Santos Rocha et al., 2016). This was supplemented with an analysis of the attributes of major crowdsourcing platforms for digital volunteers, including Tomnod, CrowdSource Rescue, Ushahidi and Open Street Maps (OSM). In this study, analysis of the literature and currently available resources identified five key attributes that are related to the motivations of digital volunteers in a crowdsourcing platform:

1. Volunteer Profile
2. Volunteer Measure of Success Shown on Profile
3. Social Network of Volunteers
4. Feedback to Volunteer

5. Social Media Post of Volunteer Task

In the survey, each attribute was varied on 3-6 levels, which are shown in Table 1. We only considered design features of a crowdsourcing platform that are most directly related to motivating factors for digital volunteers. For the sake of simplicity, we also do not consider any other user interaction or design features than those listed, and hold all other attributes constant.

Attribute	Num. of Levels	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Volunteer Profile	4	Display past experiences in volunteering	Display volunteer's location	Display volunteer's calendar	Display when volunteer is working on task		
Volunteer Measure of Success Shown on Profile	5	Rank among other volunteers	Points earned based on task completed	Money earned from tasks completed	Awards won based on tasks completed	Money earned from donations	
Social Network of Volunteers	4	View volunteers nearby	View volunteers with similar interests	View volunteers working on similar tasks	No Social Network		
Feedback to Volunteer	6	Get verification from formal organization	Earn points for accuracy in the results of tasks	Enter to win reward for highest accuracy in results among group of volunteers	Earn money per task completed	Earn money from donations depending on who sees your profile and tasks completed	Earn money based on accuracy in results of tasks
Social Media Post of Volunteer Task	4	Add to LinkedIn skills or experience	Post on Facebook	Post on Twitter	Post on Instagram		

Table 1. Levels of attributes influencing design features of crowdsourcing platform

Survey Design and Participants

A seven-part survey was designed, with a summary of its structure shown in Table 2. The sequence of different parts of the survey was designed so directly stated questions came after pairwise choice questions to reduce potential bias of preference. Specific questions were introduced as cross checks to see if respondents answered the same questions the same way again. Directly stated questions on motivation and social media use were elicited in Part VI in the survey. The survey was created and distributed using SurveyAnalytics. Informed consents from the participants were obtained at the beginning of the survey. A total of 695 participants took part in the survey. Two criteria were used to screen the data:

1. **Completeness**: Respondent data was assessed based on total completeness of survey. Incomplete questions were identified and rejected.
2. **Quality Control Questions**: Two quality control questions were included to ensure respondents did not thoughtlessly provide answers. The questions were dispersed throughout different parts of the survey and included a fixed question with a simple 'please select continue response' direction. In addition, a question from Part V was reintroduced in Part VII to cross check whether respondents answered in the same way. Respondents that did not pass all quality control questions were rejected.

This led to 389 valid responses for final data analysis. Among the valid data, demographic information of the participants is as following: 269 females, 117 males, age ranging from >18 to 60+, and 371 participants stated they reside in the United States.

Conjoint Data Analysis

A multi-nomial logit model was used to determine the conjoint part-worth values. In this model, $w(a, l)$ is the part-worth value for a particular attribute a and level l and x is an array which is equal to 1 if a specific attribute and level are present and 0 otherwise. Where U_x is the sum of the part-worths for the attributes and levels present in a configuration, this model assumes that for a choice between N configurations, the probability configuration 1 will be chosen is:

$$P_1 = \frac{exp(U_1)}{\sum_{i=1}^{N} exp(U_i)}$$

Following with this model, the choice probability of choosing the c^{th} configuration out of total C configurations in the t^{th} task for the n^{th} respondent is:

$$P_{ntc} = \frac{exp(X_{rtc}.w)}{\sum_{i=1}^{C} exp(X_{rti}.w)}$$

Part I	Introduction: general introduction of study and volunteering for disaster response
Part II	Disaster Experience Level: two questions on experience levels in an area impacted by a disaster or emergency, including if have known someone else with a first-hand experience
Part III	Preference as Volunteer for Platform: five-question pairwise choices questionnaire. Each question asks participants to choose preferred set of features of platform among five other sets of features.
Part IV	Preferece as Donor for Platform: five-question pairwise choices questionnaire. Each question asks participants to choose preferred set of features of platform among three other sets of features.
Part V	Volunteering Experience Level: two questions on experience levels in volunteering and digital volunteering for emergency or disaster situations
Part VI	Directly Stated Preferences: two questions asking motivating factors for volunteering and social media use. Question one asks participants to rank possible motivating factors if they were to volunteer in an emergency or disaster. Question two ask participants to specify level of use of various social media
Part VII	Demography: a questionnaire asking basic demographic information including age range, gender, income level, education, and residential location.

Table 2. Survey Structure

As per the algorithm by SurveyAnalytics (SurveyAnalytics, n.d.), a log-likelihood measure for all responses is used, forming a multi-dimensional non-linear continuous maximization problem. This is solved using a Nelder-Mead Simplex Algorithm to find the part-worth values. Finally, the part-worths are re-scaled so that for any attribute they have a mean of zero and then normalized for graphical representation on a percentage scale of 0 to 100 percent. The relative importance of each attribute was calculated by considering how much difference each attribute could make in the total utility of a product, where the difference is the range in each attribute's utility values. The importance measures are ratio-scaled and relative, study-specific measures. Utility value is calculated by the average of the part-worth values. Part-worths are scaled to an arbitrary additive constant within each attribute and are interval data. The equation used in this study for calculating a relative attribute importance was:

$$RelativeImportanceofAttribute = \frac{(HighestUtilityValue - LowestUtilityValueofattribute)}{\sum UtilityRangeofallattributes}$$

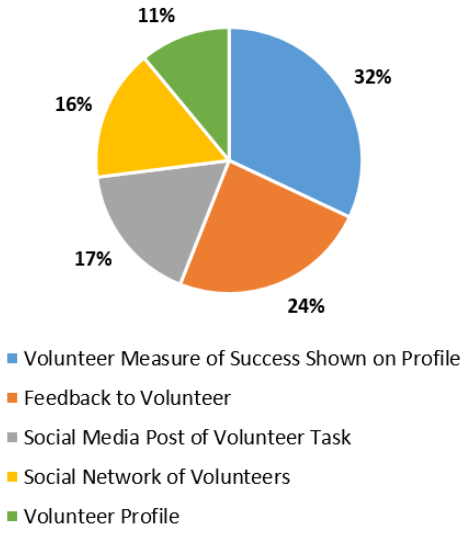


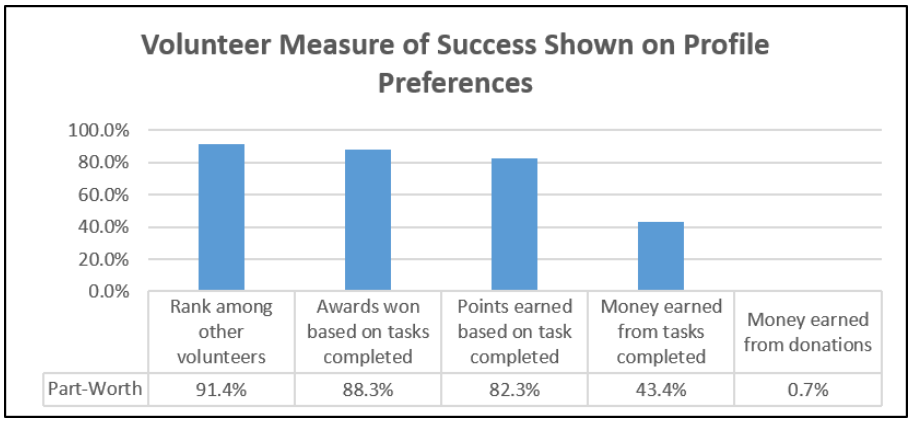
Figure 1. Relative Importance of Attributes

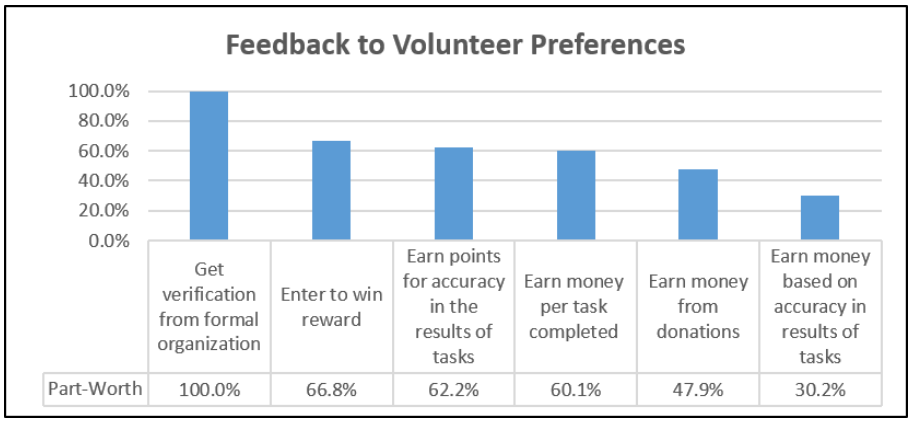
	Best Profile Levels
1.	Display past experiences in volunteering
2.	View volunteers working on similar tasks
3.	Get verification from formal organization
4.	Post on Facebook
5.	Rank among other volunteers

Figure 2. Best Profile

RESULTS

The relative importance of each attribute was calculated by considering how much difference each attribute could make in the total utility of a product. The results shown in Figure 1 are the part-worth utilities of each attribute level, which indicate the preference level of that attribute. The higher the part-worth, the more important the attribute is to the respondent. The *Volunteer Measure of Success* attribute was found as the most important followed by *Feedback to Volunteer*. The results for all attributes are shown in Figures 3 and 4. Among all the possible combinations of attribute levels, the 'best profile' made up of the most important level for each attribute is shown in Figure 2. For the top attribute of the *Volunteer Measure of Success*, the level with the highest utility (or part-worth) was *Rank among other volunteers* at 91.4% and the level with the lowest utility was *Money earned from donations* at 0.7%. For the directly stated question on motivation factors for volunteering in a disaster or emergency, the results are shown in Figure 5. The average rating of motivation factors are shown, based on participants rank ordering each factor from 1-8 (1 being highest). The motivation factor with the highest average rating was *Personal connection to area*, followed by *Give back to society* and *Make an Impact*.





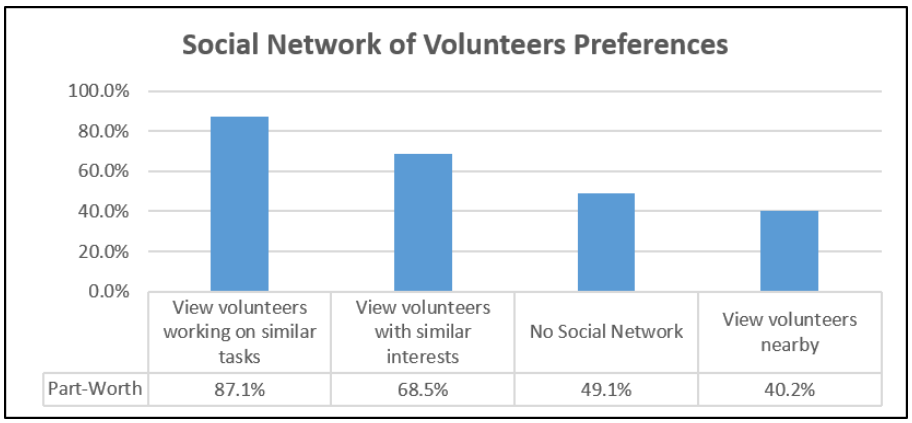


Figure 3. Average Part-Worths of Attributes of Crowdsourcing Platform: Part 1 of 2

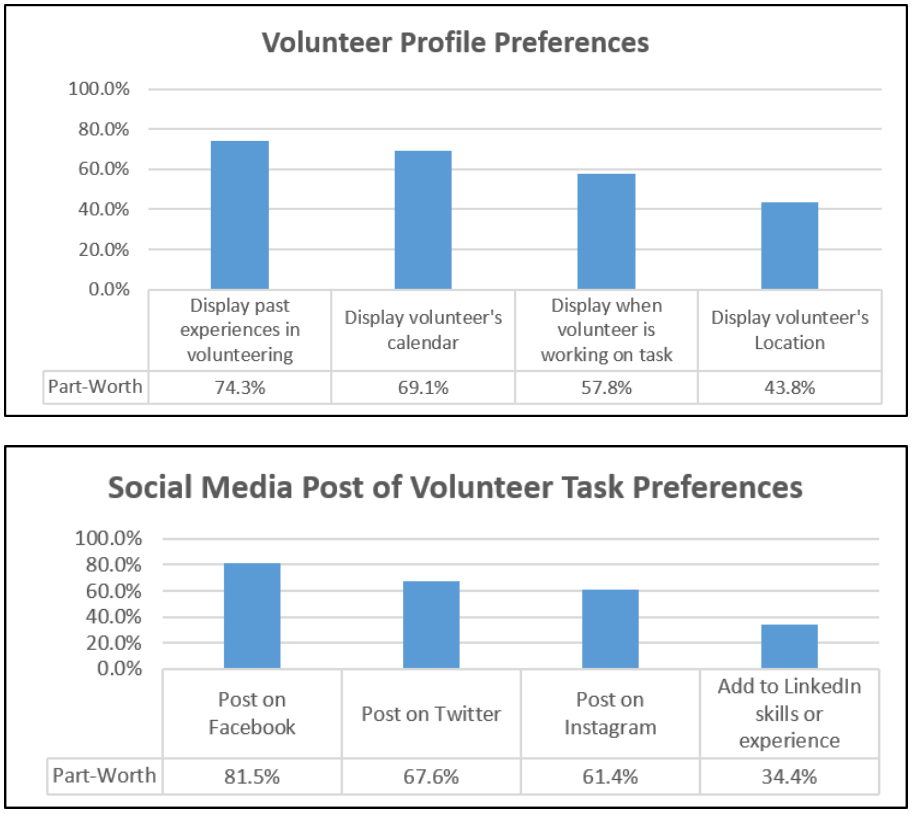


Figure 4. Average Part-Worths of Attributes of Crowdsourcing Platform: Part 2 of 2

Figure 5. Average Rank of Motivation Factors (1 being highest)

DISCUSSION AND CONCLUSION

Digital Volunteer Motivations and Design Preferences

Similar to previous studies on digital volunteer roles and motivations (Cobb et al., 2014; Baruch et al., 2016), important attributes for a crowdsourcing platform were found to be the measure of success of volunteers and the feedback provided to volunteers. Within these two attributes, the least preferred levels were those related to monetary compensation. This aligns with the directly stated results for rating of motivation factors in the survey, which found earning a reward (monetary, prizes, etc) as being rated the lowest. For the remaining three attributes of a crowdsourcing platform, the utility values for the levels within the attributes were less varied, indicating that users did not strongly prefer these certain features of a crowdsourcing platform over others. As the conjoint results

indicate, digital volunteers value understanding their success and would prefer to view this on a digital volunteer platform in the form of a rank among other volunteers or as awards won. Similarly, digital volunteers also value feedback and would prefer to view this on a digital volunteer platform in the form of verification from a formal organization or entering to win a reward. Conjoint analysis elicited such preferences of digital volunteers and revealed the importance of evaluation of a volunteer's performance. The main findings of this paper are that the future design of digital volunteer platforms should consider the importance of measuring volunteer's success and providing feedback to volunteers, particularly in a form that confirms to the volunteer that they have made a useful contribution.

Overall, this study has shown a user-centered approach can be applied to understanding digital volunteers and in the field of disaster response. Moreover, this study contributes to mixed-methods research to gain additional insight into motivations and user preferences for a set of design features that might be incorporated into an online tool specifically for digital volunteers. A limitation of this study includes that the survey used written description of features of a digital volunteer platform rather than visual depictions or examples, which may impact the understanding of respondents and preferences of features. Remaining work still needs to be done in building individual preference models, aggregated preference models, and comparing subgroups. Future work could also include different scenarios for volunteers to select motivating factors, as well as an experimental evaluation of accuracy in a digital volunteer task compared to motivating factors.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. 1122374. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

Bao, Q., Ferik, S. E., Shaukat, M. M., and Yang, M. C. (2014). "An investigation on the inconsistency of consumer preferences for product appearance: A case study of residential solar panels". In: *2014 ASME Design Engineering Technical Conferences*.

Baruch, A., May, A., and Yu, D. (2016). "The motivations, enablers and barriers for voluntary participation in an online crowdsourcing platform". In: *Computers in Human Behavior* 64, pp. 923–931.

Bjerge, B., Clark, N., Fisker, P., and Raju, E. (2016). "Technology and information sharing in disaster relief". In: *PLoS ONE* 11.9. Ed. by K.-K. R. Choo, e0161783.

Briony, J. G. (2018). "Building resilience in Small Island Developing States: social media during the 2017 Atlantic hurricane season". In: *International Conference of Information Systems for Crisis Response and Management Pan Asia 2018 (08/11/18)*.

Cobb, C., McCarthy, T., Perkins, A., Bharadwaj, A., Comis, J., Do, B., and Starbird, K. (2014). "Designing for the deluge: understanding & supporting the distributed, collaborative work of crisis volunteers". In: *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing*. ACM, pp. 888–899.

Commonwealth Telecommunications Organisation (CTO) (2006). *Using ICT for Effective Disaster Management Caribbean Forum 2006: Event Report*. Tech. rep. Ocho Rios, Jamaica: Commonwealth Telecommunications Organisation (CTO) and International Telecommunication Union (ITU).

Daniel, F., Kucherbaev, P., Cappiello, C., Benatallah, B., and Allahbakhsh, M. (2018). "Quality control in crowdsourcing: A survey of quality attributes, assessment techniques, and assurance actions". In: *ACM Computing Surveys (CSUR)* 51.1, p. 7.

Gralla, E., Goentzel, J., and Fine, C. (2014). "Assessing trade-offs among multiple objectives for humanitarian aid delivery using expert preferences". In: *Production and Operations Management* 23.6, pp. 978–989.

Green, P. E. (1974). "On the design of choice experiments involving multifactor alternatives". In: *Journal of consumer research* 1.2, pp. 61–68.

Gu, Z., Bapna, R., Chan, J., and Gupta, A. (2017). "Measuring the Impact of Crowdsourcing Features on Mobile App User Engagement and Retention: A Randomized Field Experiment". In: *Social Science Research Network (SSRN)*.

Hossain, M. and Kauranen, I. (2015). "Crowdsourcing: a comprehensive literature review". In: *Strategic Outsourcing: An International Journal* 8.1, pp. 2–22.

Kuhfeld, W. F. (2003). "Conjoint Analysis". In: *SAS Institute Publications,* available at http://support.sas.com/techsup/technote/ts689g.pdf.

Kuhfeld, W. F. (2010). "Discrete choice". In: *SAS Technical Papers, MR F* 2010, pp. 285–663.

Leidner, D., Pan, G., and Pan, S. L. (2009). "The role of IT in crisis response: Lessons from the SARS and Asian Tsunami disasters". In: 18, pp. 80–99.

Li, L. and Ulaganathan, M. N. (2017). "Design and development of a crowdsourcing mobile app for disaster response". In: *Geoinformatics, 2017 25th International Conference on*. IEEE, pp. 1–4.

Liu, S. B., Poore, B. S., Snell, R. J., Goodman, A., Plant, N. G., Stockdon, H. F., Morgan, K. L., and Krohn, M. D. (2014). "USGS iCoast – Did the Coast Change?: Designing a Crisis Crowdsourcing App to Validate Coastal Change Models". In: *Proceedings of the Companion Publication of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*. CSCW Companion '14. Baltimore, Maryland, USA: ACM, pp. 17–20.

Ludwig, T., Kotthaus, C., Reuter, C., Dongen, S. van, and Pipek, V. (2017). "Situated crowdsourcing during disasters: Managing the tasks of spontaneous volunteers through public displays". In: *International Journal of Human-Computer Studies* 102, pp. 103–121.

Meissner, A., Luckenbach, T., and Risse, T. (2002). "Design Challenges for an Integrated Disaster Management Communication and Information System". In: *The First IEEE Workshop on Disaster Recovery Networks*.

Morschheuser, B., Hamari, J., and Maedche, A. (2018). "Cooperation or competition–When do people contribute more? A field experiment on gamification of crowdsourcing". In: *International Journal of Human-Computer Studies*.

Ogie, R. I., Clarke, R. J., Forehead, H., and Perez, P. (2019). "Crowdsourced social media data for disaster management: Lessons from the PetaJakarta. org project". In: *Computers, Environment and Urban Systems* 73, pp. 108–117.

Poblet, M., Garcıa-Cuesta, E., and Casanovas, P. (2018). "Crowdsourcing roles, methods and tools for data-intensive disaster management". In: *Information Systems Frontiers* 20.6, pp. 1363–1379.

Santos Rocha, R. dos, Widera, A., Berg, R. P. van den, Albuquerque, J. P. de, and Helingrath, B. (2016). "Improving the Involvement of Digital Volunteers in Disaster Management". In: *International Conference on Information Technology in Disaster Risk Reduction*. Springer, pp. 214–224.

Sebastian, I. M. and Bui, T. X. (2009). "Emergent Groups for Emergency Response – Theoretical Foundations and Information Design Implications". In: *The Americas* 6, pp. 1–9.

Spatharioti, S. E. and Cooper, S. (2017). "On Variety, Complexity, and Engagement in Crowdsourced Disaster Response Tasks". In: *Proceedings of the 14th International Conference on Information Systems for Crisis Response And Management. Albi, France*, pp. 489–498.

SurveyAnalytics (n.d.). *Conjoint Part-Worths Calculation*.

Williams, R. C. and Phillips, A. (2014). *Information and communication technologies for disaster risk management in the Caribbean*. Tech. rep.

Yu, Z., Zhang, D., Yang, D., and Chen, G. (2012a). "Selecting the Best Solvers: Toward Community Based Crowdsourcing for Disaster Management". In: *2012 IEEE Asia-Pacific Services Computing Conference*, pp. 271–277.

Yu, Z., Zhang, D., Yang, D., and Chen, G. (2012b). "Selecting the best solvers: toward community based crowdsourcing for disaster management". In: *Services Computing Conference (APSCC), 2012 IEEE Asia-Pacific*. IEEE, pp. 271–277.

Zhang, D., Zhou, L., and Nunamaker Jr, J. F. (2002). "A Knowledge Management Framework for the Support of Decision Making in Humanitarian Assistance/Disaster Relief". In: *Knowledge and Information Systems* 4.3, pp. 370–385.

Refining a Coding Scheme to Identify Actionable Information on Social Media

Jess Kropczynski
University of Cincinnati
Jess.Kropczynski@uc.edu

Rob Grace
The Pennsylvania State University
wrg123@ist.psu.edu

Shane Halse
The Pennsylvania State University
shanehalse@gmail.com

Nathan Elrod
University of Cincinnati
natan111@mac.com

Doina Caragea
Kansas State University
dcaragea@ksu.edu

Cornelia Caragea
University of Illinois at Chicago
cornelia@uic.edu

Andrea Tapia
The Pennsylvania State University
atapia@ist.psu.edu

ABSTRACT

This paper describes the use of a previously established qualitative coding scheme developed through a design workshop with public safety professionals, and applied the schema to social media data collecting during crises. The intention of applying this scheme to existing crisis datasets was to acquire training data for machine learning. Applying the coding scheme to social media data revealed that additional subcategories of the coding scheme are necessary to satisfy information requirements necessary to dispatch first responders to an incident. The coding scheme was refined and adapted into a set of instructions for qualitative coders on Amazon Mechanical Turk. The contribution of this work is a coding scheme that is more directly related to the information needs of public safety professionals. Implications of early results using the refined coding scheme are discussed in terms of proposed automated methods to identify actionable information for dispatch of first responders during emergency incidents.

Keywords

Dispatch, Public Safety Answering Point (PSAP), Social Media, Qualitative Coding.

INTRODUCTION

Researchers have been working for almost a decade to refine methods to identify information relevant to crises posted by digital bystanders on social media (Hughes & Palen, 2009; Imran, Elbassuoni, Castillo, Diaz, & Meier, 2013). Recently, new fieldwork with 9-1-1 call-takers at Public Safety Answering Points (PSAPs) in the United States has extended this work by identifying information requirements necessary to dispatch first responders (Kropczynski et al., 2018). Understanding information requirements is a helpful as a first step to automating methods to identify actionable information on social media such as requests for assistance and enhancing situational awareness (Vieweg, 2012). In this paper, we describe early work to apply these information requirements to social media data collected during crises using qualitative coding. We begin by describing the 6W (Where, What, Weapons, When, Who, Why) information requirements that must be satisfied to dispatch first responders identified through a design workshop with public safety professionals at a PSAP in the United States (Kropczynski et al., 2018). We then use manual coding to identify information satisfying these requirements in social media posts. Results are used to refine this coding scheme. Finally, we used the refined manual coding scheme to code social media data and develop insights about next steps to automate the detection of actionable information using machine learning techniques.

Previous work in coding and classifying information posted to social media has identified information that is informative (Imran et al., 2013), enhances situational awareness (Vieweg, 2012), or general relatedness to a crisis (Olteanu, Castillo, Diaz, & Vieweg, 2014). These works have evolved over several years to allow the development of machine learning classifiers used to automate detection of social media data that may be useful for situational awareness (Caragea, Silvescu, & Tapia, 2016; Herndon & Caragea, 2016). Equally important to these efforts are works to filter irrelevant information from bots (Wang et al., 2014), or to sort posts by news sources and external observers (Olteanu, Vieweg, & Castillo, 2015; Starbird, Palen, Hughes, & Vieweg, 2010). Despite this evolution, PSAPs in the United States do not currently utilize protocols that detect and respond to requests for assistance that are posted to social media. Instead, dispatch of first responders is based on information gathered through phone calls. In this trajectory to refine automated detection of useful information, it is important to consider the information requirements to dispatch first responders to a crisis.

Today, PSAP call-takers use computer-aided software to gather information from individuals that call 9-1-1, such as ProQA (https://prioritydispatch.net/discover_proqa/). ProQA software provides 9-1-1 call-takers with scripts that distill caller information into emergency types and results in the dispatch of firefighters, law enforcement, medical responders, or other first responders to resolve the request for assistance. Logic used by ProQA is rather complex, however, prior to the use of computer-aided software, 9-1-1 call takers utilized a basic information gathering protocol called the 5W's/6W's, in which call takers ask 1) *where* is the incident taking place, 2) *what* is the nature of the incident, 3) are there *weapons* involved, 4) *when* did the incident occur/is the incident ongoing, and 5) *who* is involved or how many people are involved. Some protocols include a sixth W, which retains any information about *why* the incident occurred. Table 1 shows the results of previous fieldwork with PSAP call takers, dispatchers, and first responders worked create a qualitative coding scheme to identify social media posts that contain information that is necessary to determine emergency types and send first responders to emergency locations.

Table 1. Original 6W Qualitative Coding Scheme (Kropczynski et al., 2018)

Label	Coding	Representative Examples in Fieldwork
Where	Place where help is needed; where an incident occurred; location of victim/suspect/witness; Directional guides/points of reference	"Northland Mall parking garage"; "in the corridor at univ high"; "@ st philip & george"; "headed west on I-26 at Ashley Phosphate"
What	Type of incident; indications of severity	"car accident"; "boat on fire lots of flames"
Weapons	Indication of whether weapons are present and if so, the type of weapons present	"#shooting"; "assault rifle"; "gun"
When	Time the incident occurred; indication of whether incident is still occurring; time lapse	"just now"; "7:32am"
Who	Number of people injured, or number of people armed; Description of victim/perpetrator/vehicle ; nature of observer (firsthand vs. secondhand account)	"3 injured"; "2 armed men"; "tall skinny white guy in blue jeans and a white v-neck tee.. 20 yrs old-ish.. Brown hair"; "we"
Why	Chain of events that led to emergency; Rationale for occurrence that may be helpful to an investigation	No examples

The 6W coding scheme has been applied to fictional social media posts generated by professionals working within a PSAP that were asked in a design workshop to "…construct a 280-character Tweet (Twitter's current character limit) that they perceived was descriptive enough for someone in their professional position to take action on" (Kropczynski et al., 2018). For each of these information labels, previous work has been identified to mine social media data for location information (Bilhaut, Charnois, Enjalbert, & Mathet, 2003; Daly & Thom, 2016; Grace et al., 2017; Han, Cook, & Baldwin, 2014; Intagorn & Lerman, 2010; Quercini, Samet, Sankaranarayanan, & Lieberman, 2010), incident types (Herndon & Caragea, 2016; Li, Caragea, Caragea, & Herndon, 2018; Mouzannar & Awad, 2018), using bag of word techniques or convolutional neural networks (Caragea et al., 2016) may be used to detect presence of weapons, timestamps aid in the identification of when an incident occurred, but no tools currently combine these techniques into one tool. This paper describes early work to move the trajectory of identification of actionable information forward in order to create such a tool.

Research Question

Although the 6W coding scheme has been applied to fictional social media posts, it has not yet been applied to social media posts generated during a crisis. The overarching research question guiding this work is: When applied

to social media posts generated during a crisis, does the 6W coding scheme help to identify information that is actionable for dispatch of first responders according to previously established information requirements?

METHODS

The primary objective of this research is to verify the application of the 6W coding scheme to social media posts generated during a time a crisis using qualitative coding. As a large, pre-labeled dataset, the CrisisLex T6 dataset (Olteanu et al., 2014) was viewed as a viable dataset for the purposes of this analysis. The dataset contains data collected from Twitter during 6 different disasters between October 2012 and July 2103 in English-speaking countries. For each of these incidents, randomly selected tweets have been pre-filtered to label data as related/not related to a disaster, and either informative/not informative. Although this dataset has since been criticized when applied to establish, machine learning classifiers due to methods employed to collect data, for our purposes, our intention is only to qualitatively observe the presence of 6W information in social media generated during a crisis. The purpose of this activity is detection, but coding of relevant and informative data in order to establish whether the 6W coding scheme can be used to satisfy information needs of dispatch.

In the CrisisLex T6 dataset, 3926 tweets have been labeled as both related and informative to the crisis that they were collected during. Our method is to qualitatively code these pre-labeled tweets using the 6W coding schema. For each of these tweets, trained qualitative coders were asked to review contents, and if present, copy and paste the contents of tweets related to one the W's according to the coding schema into an associated column of a spreadsheet. The purpose of retaining content rather that indicating presence/absence of the W was to review the way that each of these W's are represented in actual tweets. In addition, there was some hope that text related to each W label might be used for training purposes for machine learning.

RESULTS

Results showed that the majority of tweets labeled in the CrisisLex T6 dataset as informative and relevant contained *where*, *what*, *who*, and *why* information. Less prevalent was information related to *weapons* and *when*, however this varied by incident as only 2 of six incidents would be expected to mention *weapon* information (Boston Bombing and LA Airport Shooting). The low incidents of *when* information was anticipated because the implication of many tweets is that the information being posted is currently happening.

Table 2. Percent of Tweets Labeled by 6Ws

W Label	Percent
Where	78%
What	88%
Weapons	3%
When	5%
Who	68%
Why	72%

Although, the application of the 6W qualitative coding scheme demonstrated that many of the W's are present in these tweets, examination of the content contained in these tweets showed that very few tweets contained information requirements to dispatch first responders. Beginning with *where* information, this is necessary to identify a location to dispatch first responders. As written in the original coding scheme, *where* information is quite broad in its' description. This resulted in the contents of this coding to frequently include the name of a state, region, or town. Although this type of information may be quite helpful for situational awareness, it is the case that few tweets contained information that would satisfy the requirement of identifying a location where a first responder may be sent.

What information was present in the majority of tweets, however, the information requirement that this information must satisfy is to identify statements that can be associated with a type of incident to help understand the type of first responder to be deployed (fire, law enforcement, medical). As written, qualitative coding resulted in many statements that simply reiterated the subject of the tweet rather than information that helped identify a specific incident. Of all 6Ws, *weapons* information was most accurately coded in line with information aims—identifying the presence or absence of a weapon. *Who* information typically took the form of an @mention of another Twitter user, although a small number of tweets contained the number of victims or perpetrators involved in an incident. Finally, *why* information frequently included statements that were duplicated in *what* information, for example, "mandatory evacuations" may be *what* is happening in one tweet and the reason *why* is "flash flooding," however, flooding may also be considered *what* information. Based on these results, it was determined that the use of the 6W coding scheme, as written was not useful to identifying actionable information for dispatch.

REFINEMENTS TO CODING SCHEME

These early results indicated to our research team that further refinements to the coding scheme in terms of subcategories for each of the 6Ws would be necessary to focus on stratifying PSAP dispatch information requirements. The subcategory coding schemes contain subcategories that are intended to only focus on actionable information, provide a specific coding criteria, and examples borrowed from actual tweets in the dataset. Further, we have reduced the 6W coding scheme to a 5W coding scheme by eliminating the *why* information category due to the lack of actionable information for dispatch that is typically present in this category. These subcategories have been tested for clarity with qualitative coders on Amazon Mechanical Turk, but future work will be conducted to better understand the presence of these tweets within a larger dataset. Only a small sample of 200 tweets from the CrisisLex T6 dataset were used for the purposes of understanding if subcategories would be a viable method to refine the coding scheme.

Qualitative coders were given the following instructions: For each tweet, the coder should copy and paste words from the tweet that match the particular subcategory, if the information is present. If not present, the form should be left blank. Please keep in mind that the goal of this work is to help identify information that will be relevant to first responders during an emergency event. If something in a tweet seems important for a first responder to know, but does not fit into a category, please make a note under the "other" category. Also, if you find some of the coding descriptions confusing or misleading, you can also list that information under the "other" category.

Subcategories are described in sections that follow:

Where Information Subcategory Coding Scheme

Our results showed that state, region, and town are often considered as *where* information and although useful to situational information, it is assumed that in a tool that is used by dispatch, social media posts will likely be aggregated from a particular city, town, or regional bounding box. Therefore, tweets relating to an entire state is simply too broad to be actionable in most cases. The coding scheme subcategories have been updated as follows:

Subcategory:	Street address
Coding:	(If present, please write) Number of building and name of street
Example:	123 Main St.; 456 East Ave.; 789 MLK Rd.
Subcategory:	Building name
Coding:	(If present, please write) Name of well-known building
Example:	Sears Tower; Kirkland Mall; the Courthouse
Subcategory:	Location within building
Coding:	(If present, please write) If building name is known, this information specifies a floor, room, or orientation within a building
Example:	Near the east entrance; the southwest corner of the building; Near Taco Bell in the Mall
Subcategory:	Intersection
Coding:	(If present, please write) Location of incident in the form of the intersection of two streets. Both streets must be named to be an intersection.
Example:	Main and Vine; Main St. and Vine St.
Subcategory:	Words that indicate a moving target (vehicle in motion)
Coding:	(If present, please write) direction of moving target (i.e. north, south, east, west) or area that moving target is heading in the direction of (i.e. toward Main St.; toward Taco Bell)
Example:	headed north on Main Street; took off in the direction of Taco Bell
Subcategory:	Situational awareness in neighborhood/city/region
Coding:	(If present, please write) Name of neighborhood, city, or region
Example:	Highland Neighborhood; Townville, Low Country

Information that is not actionable: reference to state

By employing the above subcategories, none of the coders indicated that coding information are unclear. Results showed that the sample of 200 tweets contained 19 street addresses, 12 building names, 3 locations within a building, 7 intersections, 3 moving targets, and 90 tweets that contained information that may be useful for situational information.

What Information Subcategory Coding Scheme

Results of original coding scheme found that *what* information was often interpreted as the subject of the sentence, based on this result, two subcategories were created to better satisfy information requirements for dispatch. These subcategories asked qualitative coders to specifically identify requests for assistance and words that indicate there is an emergency situation or a situation that can/should be addressed by a first responder.

Subcategory:	Request for assistance
Coding:	(If present, please write) Information that relates to the type of assistance being requested - or full request for help
Example:	in need of rescue; building collapse; stranded
Subcategory:	Words that indicate there is an emergency situation or a situation that can/should be addressed by a first responder
Coding:	(If present, please write) Information about a crisis event taking place
Example:	Fire, flood, crash

None of the coders indicated that the coding scheme for these subcategories are unclear. Of the 200 tweets coded, 10 contained requests for assistance and 143 contained information that coders believed would be useful information for first responders. This information often contained very general words such as "flood", "shooting", or "wildfire" which indicates that this category should be further explored. In many instances, it is simply the case that the tweet did not originate from an eyewitness or victim of an event, but instead originated from a news source or outside observer of the event on social media. Techniques currently being used to better filter tweets by eyewitnesses (Caragea, Squicciarini, Stehle, Neppalli, & Tapia, 2014; Li et al., 2018) will help to further refine work in this category.

Weapons Information Subcategory Coding Scheme

Although this category already produced useful information, we attempted to further refine to two subcategories in line with information requirements which includes information that indicates a weapon is present and words that indicate what kind of weapon is present.

Subcategory:	Words that indicate that weapon is present
Coding:	(If present, please write) This information may simply indicate that a weapon is present, but does not indicate what kind of weapon
Example:	shooter, shots, explosion, loud pops
Subcategory:	Words that indicate what kind of weapon is present
Coding:	(If present, please write) Indication of type of weapon present
Example:	gun, bomb, rifle, AK47, baseball bat, mace, tire iron

None of the coders indicated that the coding scheme for these subcategories are unclear. Of the 200 tweets, 66 related to incidents where a weapon may have been present (Boston Bombing and LA Airport Shooting). Of those, 61 contained information coded was words indicating that a weapon is present and 11 contained words that indicate what kind of weapon is present. In the case of the kind of weapons present, many wrote "bomb" or "rifle," based on this result, a bag of words technique where weapon types are pre-loaded may be more useful for detection of this subcategory. None of the tweets from incidents related to natural disasters (wildfires, flooding) contained information coded as *weapons* information.

When Information Subcategory Coding Scheme

This category was further refined into three subcategories, information that indicates that a situation is ongoing, happened in the past, or will happen in the future.

Subcategory:	Indication that situation ongoing
Coding:	(If present, please write) Any information that indicates that the situation still requires the help of a first responder
Example:	Just now, a minute ago, breaking, latest, exact time mentioned by user, but not the timestamp of tweet
Subcategory:	Indication that situation happened in the past
Coding:	(If present, please write) Any information that indicates that the situation happened in the past and may not still require the help of a first responder
Example:	earlier today, yesterday, ambulance just left, but not the timestamp of tweet

Subcategory: Indication that situation may occur in the future
Coding: (If present, please write) Any information that indicates that there is an impending threat of emergency that is about to occur and will require the help of a first responder
Example: threat, headed this way, worried about possible

None of the coders indicated that the coding scheme for these subcategories are unclear. Of the 200 tweets coded, 15 contained information that indicated that a situation is ongoing, 10 contained information that indicated a situation happened in the past, 11 contained information that indicated a situation may occur in the future.

Who Information Subcategory Coding Scheme

Results of our analysis showed that *who* information may be interpreted as an original poster of a tweet, news source or agency mentioned in a tweet, which is not often actionable information. Subcategories focused on actionable information now indicate who is in need of assistance and who is the perpetrator.

Subcategory: Who needs assistance
Coding: (If present, please write) Any description of a person in need that will help a first responder identify them, or information that will help a dispatcher identify number of resources to send to the scene
Example: Lady on ground, person in red car, three children, a busload of people

Subcategory: Who is the perpetrator
Coding: (If present, please write) Any description of a person that law enforcement or a first responder should be aware of
Example: Person in yellow jacket; black SUV

None of the coders indicated that the coding scheme for these subcategories are unclear. Of the 200 tweets, 21 contained information related to who is in need of assistance. None of the tweets contained information about a perpetrator.

Other Information Identified During Coding

As mentioned in the coding instructions, Amazon Mechanical Turkers were given the option to share any information that they thought may be important to a first responder but does not fit into any category. They were also encouraged to state any notes related to coding instructions that may have been confusing or misleading. None of the coders stated that coding instructions were confusing or misleading. Some coders included words that seemed useful to situational awareness for citizens such as “emergency declaration” or “campus closed” but no theme emerged that led to the inclusion of a new category.

CONCLUSION AND FUTURE WORK

Based on these results, we believe that the 5W coding scheme with categories included show promise for the development of tools to automate detection of actionable information. While this is the case, of the 200 tweets coded for refinement of this coding scheme, few contained actionable information. An original aim of this work was to utilize actionable information present in social media posts generated during a crisis, however, in attempting to identify these tweets for machine learning training using manual coding, we found that the dataset we have utilized contained few incidents of actionable information. For many of the subcategories, other techniques or dataset may be useful for the automated coding of actionable information that does not require large datasets of actionable information. These subcategories include: street address, building name, intersection, neighborhood/city/region, presence of a weapon, type of weapon, and past/present/future tense words. Categories that will need attention in the future include requests for assistance. Existing presorting techniques may be employed before attempting to find this type of data in future work.

ACKNOWLEDGMENTS

We thank The Charleston County Consolidated 911 Center for their time and collaboration in this work. Mission Critical Partners (https://mcp911.com/) was also instrumental in supporting travel for design workshops, helping us to coordinate this work, and to interpret results and implications. This material is based upon work supported by the National Science Foundation under Grant Nos. (541155 & 741370).

REFERENCES

Bilhaut, F., Charnois, T., Enjalbert, P., & Mathet, Y. (2003). Geographic reference analysis for geographic document querying. *Proceedings of the HLT-NAACL 2003 Workshop on Analysis of Geographic*

References, 55–62. https://doi.org/http://dx.doi.org/10.3115/1119394.1119403

Caragea, C. ., Squicciarini, A. ., Stehle, S. ., Neppalli, K. ., & Tapia, A. . (2014). Mapping moods: Geo-mapped sentiment analysis during hurricane sandy. *ISCRAM 2014 Conference Proceedings - 11th International Conference on Information Systems for Crisis Response and Management*, (May), 642–651. Retrieved from http://www.iscram.org/legacy/ISCRAM2014/papers/p29.pdf

Caragea, C., Silvescu, A., & Tapia, A. (2016). Identifying informative messages in disaster events using convolutional neural networks. *ISCRAM 2016 Conference Proceedings – 13th International Conference on Information Systems for Crisis Response and Management*, (May). Retrieved from http://idl.iscram.org/files/corneliacaragea/2016/1397_CorneliaCaragea_etal2016.pdf

Daly, S., & Thom, J. A. (2016). Mining and Classifying Image Posts on Social Media to Analyse Fires. *13th International Conference on Information Systems for Crisis Response and Management*, (May), 1–14.

Grace, R., Kropczynski, J., Pezanowski, S., Halse, S., Umar, P., & Tapia, A. (2017). Social triangulation: A new method to identify local citizens using social media and their local information curation behaviors. In *Proceedings of the International ISCRAM Conference* (Vol. 2017–May).

Han, B., Cook, P., & Baldwin, T. (2014). Text-based twitter user geolocation prediction. *Journal of Artificial Intelligence Research*, *49*, 451–500. https://doi.org/10.1613/jair.4200

Herndon, N., & Caragea, D. (2016). An evaluation of approaches for using unlabeled data with domain adaptation. *Network Modeling Analysis in Health Informatics and Bioinformatics*, *5*(25). https://doi.org/https://doi.org/10.1007/s13721-016-0133-6

Hughes, A. L., & Palen, L. (2009). Twitter adoption and use in mass convergence and emergency events. *International Journal of Emergency Management*, *6*(3/4), 248. https://doi.org/10.1504/IJEM.2009.031564

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., & Meier, P. (2013). Practical extraction of disaster-relevant information from social media. In *Proceedings of the 22nd International Conference on World Wide Web - WWW '13 Companion*. https://doi.org/10.1145/2487788.2488109

Intagorn, S., & Lerman, K. (2010). Harvesting Geospatial Knowledge from Social Metadata. *Proceedings of the 7th International ISCRAM Conference*, (May), 1–10. Retrieved from http://www.isi.edu/integration/papers/intagorn10-iscram.pdf

Kropczynski, J., Grace, R., Halse, S., Obeysekare, E., Bénaben, F., & Tapia, A. (2018). Identifying Actionable Information on Social Media for Emergency Dispatch. *In Proceedings of ISCRAM Asia Pacific 2018*.

Li, H., Caragea, D., Caragea, C., & Herndon, N. (2018). Disaster response aided by tweet classification with a domain adaptation approach. *Journal of Contingencies and Crisis Management*, *26*(1), 16–27. https://doi.org/10.1111/1468-5973.12194

Mouzannar, H., & Awad, M. (2018). Damage Identification in Social Media Posts using Multimodal Deep Learning, (May).

Olteanu, A., Castillo, C., Diaz, F., & Vieweg, S. (2014). CrisisLex: A Lexicon for Collecting and Filtering Microblogged Communications in Crises. *Proc. of the 8th International Conference on Weblogs and Social Media*, 376. https://doi.org/10.1.1.452.7691

Olteanu, A., Vieweg, S., & Castillo, C. (2015). What to Expect When the Unexpected Happens: Social Media Communications Across Crises. *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing - CSCW '15*, 994–1009. https://doi.org/10.1145/2675133.2675242

Quercini, G., Samet, H., Sankaranarayanan, J., & Lieberman, M. D. (2010). Determining the spatial reader scopes of news sources using local lexicons. *Proceedings of the 18th SIGSPATIAL International Conference on Advances in Geographic Information Systems - GIS '10*, 43. https://doi.org/10.1145/1869790.1869800

Starbird, K., Palen, L., Hughes, A. L., & Vieweg, S. (2010). Chatter on the red: what hazards threat reveals about the social life of microblogged information. *CSCW '10 Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work*, 241–250. https://doi.org/10.1145/1718918.1718965

Vieweg, S. (2012). *Situational Awareness in Mass Emergency: A Behavioral and Linguistic Analysis of Microblogged Communications*. University of Colorado at Boulder.

Wang, A. H., Hai, A., Detecting, W., Bots, S., Networking, S., Machine, S. A., & Wang, A. H. (2014). Detecting Spam Bots in Online Social Networking Sites : A Machine Learning Approach To cite this version : HAL Id : hal-01056675 Detecting Spam Bots in Online Social Networking Sites : A Machine Learning Approach, 0–8.

Real-time Adaptive Crawler for Tracking Unfolding Events on Twitter

Asmelash Teka Hadgu
L3S Research Center
Hannover, Germany
teka@L3S.de

Sallam Abualhaija
Interdisciplinary Centre for Security, Reliability and Trust
Luxembourg, Luxembourg
sallam.abualhaija@uni.lu

Claudia Niederée
L3S Research Center
Hannover, Germany
niederee@L3S.de

v1.1.1
2018/09/10

ABSTRACT

When a major event such as a crisis situation occurs, people post messages on social media sites such as Twitter, in order to exchange information or to share emotions. These posts can provide useful information to raise situation awareness and support decision making, e.g., by aid organizations. In this paper, we propose a novel method for social media crawling, which exploits a Bayesian inference framework to keep track of keyword changes over time and uses a counter-stream to gauge the inclusion of noise and irrelevant information. In addition, we present a framework to evaluate real-time adaptive social search algorithms in a reproducible manner, which relies on a semi-automated approach for ground-truth construction. We show that our method outperforms previous methods for very large scale events.

Keywords

adaptive crawler, real-time adaptive search, event tracking, crsis communication

INTRODUCTION

Nowadays, social media platforms have become an essential communication tool since they provide an open medium on a diverse spectrum of topics. As an accessible and near real-time reflection of such events and their perception, Twitter has attracted the attention of many researchers across different domains. Twitter content analysis is useful for different applications including but not limited to detecting customers' reactions towards a product (Chen et al. 2013), analyzing public political polarities (Conover et al. 2011), predicting election results (Tumasjan et al. 2010), monitoring news (Magdy 2013), identifying and analyzing researchers (Hadgu and Jäschke 2014) and crisis management (Castillo 2016). As a foundation for those analyses, the task of adequately collecting relevant content for an event of interest, has also gained some interest in the research community recently.

Since manually checking and changing keywords as an event unfolds, requires a lot of effort and is inefficient, different automatic query keywords adaptation strategies have been proposed (Wang, Tokarchuk, Cuadrado, et al. 2013; Magdy and Elsayed 2014; Sadri et al. 2016) to monitor unfolding events on Twitter. All different adaptive search methods try to adapt the search keywords as the event evolves through out the search process. An intuitive method is to consider the most frequent hashtags that appear in a time interval and use them as the next query keywords. However, this technique has major limitations. In particular, many people exploit trending hashtags through hashtag hijacking (Hadgu, Garimella, et al. 2013) to diffuse opposing views and unrelated content, e.g., marketing companies take advantage of frequent hashtags to promote their ads. Another problem is that the same

hashtag could be used for different events that may happen at the same time. The role of the adaptive search systems is to retrieve as many relevant tweets as possible without introducing too much noise.

Therefore, more advanced techniques that consider correlation of keywords to the underlying event or those based on text content similarity measures are applied to capture promising query keywords that preserve relevant content. In this paper, we present a novel adaptive crawling approach for Twitter which can be used to track a particular event in real-time. The adaptive crawler starts with a set of seed keywords given manually by the user. In contrast to existing methods, it does not rely on the filtered stream generated based on this keyword set (and its modifications over time) alone. It complements this stream with a second stream, an unfiltered sample stream, which is used as a kind of "counter-stream" to help eliminate keywords from co-occurring events. A Bayesian framework is used to identify new keywords based on both streams.

The absence of a robust evaluation framework to compare the performance of alternative real-time adaptive algorithms is a challenge. There are no standard benchmarks to compare the performance of different adaptive algorithms. Especially, evaluating the coverage or recall of a method is difficult, since the size and speed of the Twitter stream makes it impossible to capture the whole data set for a time frame - besides the limitations enforced by Twitter on the publicly available tweets. We evaluate our approach, compare and contrast it with related work mainly on the Berlin Attack 2016 [1]. For this crisis, we systematically constructed the ground truth in order to evaluate the various adaptive crawling methods. The method can be employed for creating further ground-truth data sets in an effective, semi-automatic fashion. The evaluation considers two dimensions, the temporal aspect demands the algorithm to adapt new relevant keywords as soon as they emerge. The other dimension includes the standard metrics; precision, recall and F1-measure of the retrieved relevant tweets.

In this work, we address the real-time adaptive search task within crisis management context. Our choice is motivated by several reasons. First, the proposed system has been developed within a research project dedicated to communication concepts during crises. Hence, we were able to involve practitioners from aid organizations into our requirements analysis, development and evaluations, strengthening the evaluation results. The outcome is an application called **Sover!** short for Social media observer (Hadgu, Abualhaija, et al. 2018). The system has been tested in real scenarios. Second, crisis management is an extremely important and challenging application with a growing role for social media (Castillo 2016). The temporal aspect is very important and the reliability of crawling results is weighed by the sensitivity of critical decisions made, at least partially, based on these results.

In summary, our main contributions are:

- An effective real-time adaptive search algorithm that leverages simultaneously both the public one percent Twitter stream and the Twitter filter stream and combines them using a Bayesian framework for improving recall as well as precision.
- A simulation environment to experiment with real-time adaptive search algorithms on Twitter in a reproducible manner.
- A well-defined strategy on how to construct a ground truth specific to evaluate the performance of real-time adaptive search algorithms on Twitter.

RELATED WORK

The work in this paper builds on two distinct yet complementary tasks. The first is how to search for relevant content to a specific event in social media. The second is how to apply these methods for a real application context, crisis management in our case. Therefore, we describe the related work corresponding to each task separately.

Real-time Adaptive Search. In (Wang, Tokarchuk, Cuadrado, et al. 2013), the authors proposed an adaptive crawling algorithm, Refined Keyword Adaptation (RKwA), by developing a recall-oriented query that exploits the emerging popular hashtags in the crawling method. In their follow-up (Wang, Tokarchuk, and Poslad 2014), the authors proposed an adaptive crawling method that monitors hashtags and rates them by their similarity to the initial seeds using TF-IDF weighting. In (Magdy and Elsayed 2014; Magdy and Elsayed 2016), the authors developed an unsupervised adaptive method to track tweets for a dynamic topic. A binary classifier is trained and updated automatically and regularly to detect more relevant tweets from the stream. Another work, relevant to ours, is (Sadri et al. 2016), the Tweet Acquisition System (TAS), a system that follows an iterative process to automatically change and adapt the query representing a temporal topic aiming at maximizing the recall. The main difference between **Sover!** and these approaches is that while all these methods rely on a filter stream, to do the adaptation, **Sover!** uses simultaneously the sample stream to better estimate relevant keywords.

[1] https://en.wikipedia.org/wiki/2016_Berlin_attack

Social Search for Crisis Communication. Several tools have been developed to monitor social media for Crisis Communication. Let us have a brief look at the ones that are closest to our work. Rogstadius et al. proposed CrisisTracker, an online real-time system that tracks keywords on Twitter during disasters and creates stories using clustering. The Twitter Streaming API is used to collect tweets based on some keywords provided by the user. Twitcident (Abel et al. 2012) is a web framework that relies on the emergency broadcasting services to enable detecting an incident automatically and monitoring relevant information diffused on Twitter. XHelp in (Reuter et al. 2015) is a cross-social-media application that supports volunteers in responding to disasters. It is implemented as an embedded Facebook application. Magdy developed TweetMogaz, a news portal of tweets in the Arabic regions including Syria and Egypt. TweetMogaz provides a summary of the public response in Twitter towards ongoing events. The Emergency Analysis Identification and Management System (EAIMS), proposed by by McCreadie et al., is a crisis tracking toolkit, that provides a real-time event detection as well as some other relevant functions like sentiment analysis, information credibility estimation and automatic time-line generation. **Sover!** builds on ideas from these applications. It starts with Twitter but expands to Facebook pages, YouTube links and news pages associated with the tweets, which are significant for relief organizations.

ARCHITECTURE

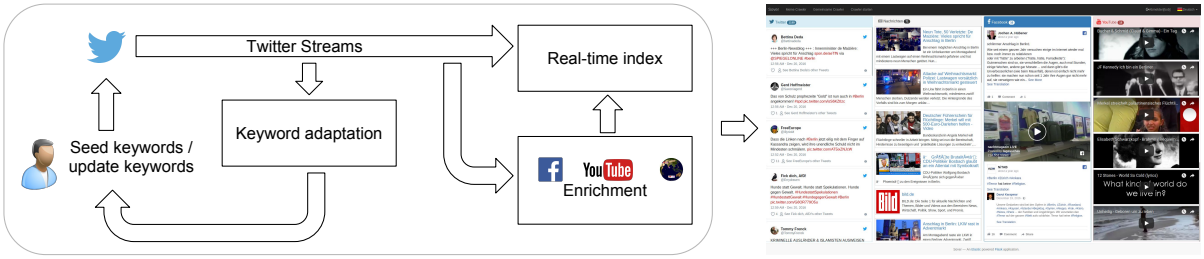


Figure 1. System Architecture of Sover!

In this section, we present the overall architecture (cf. Figure 1) and the various components of our adaptive search system **Sover!** . To start monitoring an event, a user begins the search by supplying a typically small set of initial seed 'keywords' that describe the event. E.g., to monitor social media feeds about the Berlin attack in German, one might supply 'Berlin Anschlag' ('Berlin Attack'). The system uses Twitter streams to search tweets containing these initial search terms initially. After a small time interval, the system dynamically changes the query keywords. The keyword adaptation module is used to compute these changes. A dashboard of social feeds from different platforms presents social media posts on the event to the user. A real-time indexing module and URL expansion and enrichment module support this dashboard. Each of these components is discussed below.

Twitter Streams. Sover! leverages the real-time Twitter streaming API to monitor events in real-time. This is mainly done through the **Filter Stream** [2] in combination with the **Sample Stream** [3]. The **Filter Stream** allows a searcher to supply parameters such as track to filter feeds by keywords, follow to filter by accounts or location to use bounding boxes to filter tweets from a specific area. These parameters can be changed in real-time to reflect the changing nature of an evolving event. Our system also supports searching past events. This employs data from Twitter Advanced Search [4]. The Twitter Advanced Search serves as a gateway to tap into the entire index of tweets. In order to obtain similar payload as a searcher gets from the **Filter Stream**, we combine this with the Twitter status look-up API [5]. We describe our implementation in the Evaluation Framework Section.

Keyword Adaptation. The main task of the keyword adaptation module is to take in two streams, the sample stream and filter stream and perform a statistical analysis on these collections in order to include new keywords that emerge from the collection to add in the next iteration or drop keywords from the previous query that are no longer relevant as search terms. The decision whether to update the query keywords or not takes place at discrete intervals. For instance, for a real-time event, after initialization through the user, we observe the stream for a time window, e.g., 5 min, then see if there are emerging keywords that should be included in the subsequent request to the stream. We also check if keywords in the search query are still relevant. The method behind this module is the main contribution of this paper. The keyword adaptation algorithm is presented in detail in the next Section.

[2] https://stream.twitter.com/1.1/statuses/filter.json
[3] https://dev.twitter.com/streaming/reference/get/statuses/sample
[4] https://twitter.com/search-advanced
[5] https://dev.twitter.com/rest/reference/get/statuses/lookup

URL Enrichment. Twitter posts contain URLs to original sources such as images, videos that users upload from their devices but also shared links pointing to other social media platforms, news and other websites. Most of these URLs are shortened either by Twitter for display or by users using URL shortening services. Working with these shortened URLs is challenging. The URL enrichment module helps mitigate this problem. First it performs URL unshortening by performing an HTTP HEAD request. This not only serves as a way to check if the URL is valid but also to categorize links by domain. We mainly categorize domains as Twitter, Facebook, YouTube! and News Media. We use domains harvested from the GDELT project [6] to curate a list of news media domains. This helps to present content using an intuitive social feeds dashboard when monitoring events. For valid URLs pointing to news resources, this module also enriches the URLs with meta-data: such as article title, intro, and images if any to provide a snippet.

Real-time Index. We index the filtered and enriched streams of tweets on the fly using ElasticSearch [7]. We provide a mapping for tweets that makes it easy to recognize date-time, location fields etc. This helps to provide faceted search over all the Twitter fields as they get indexed in real-time from the social feed dashboard.

Human in the Loop. As the event a user is tracking unfolds, the keyword adaptation module provides new emerging keywords or omits those that are not relevant anymore from the set of search keywords. This happens automatically. Additionally, there is the option to bring the Human in the Loop: the user can intervene at any point via the user interface, if she thinks that the system adds noisy or irrelevant keywords or drops an important keyword. **Sover!** provides a user interface for the user to monitor and modify query keywords in a running crawler as necessary.

METHODOLOGY

Event tracking on Twitter is essential for many real-time applications. The dynamic nature of Twitter however makes real-time adaptive search challenging to achieve good coverage that guarantees gathering relevant tweets, without drifting away to other events happening at the same time. In this section, we present a novel adaptive search method for tracking dynamic events on Twitter and a simulation framework to evaluate such adaptive algorithms.

Real-time Adaptive Search

Let ς be a social media stream that consists of a set of social media feeds (posts) about a variety of events. Let us further assume that we can search this stream using query keywords $\varkappa$ to retrieve posts containing any of these keywords that describe an event ε that we are interested to track in real-time.

Definition 1 Filter Stream, F : a set of posts retrieved from ς using $\varkappa$.

Definition 2 Sample Stream, S : a random sample of posts from ς.

Problem Statement. Given the sub streams F and S, and a set of query keywords $\varkappa_i$ at a given time T_i, generate a set of query keywords $\varkappa_{i+1}$ to maximize the retrieval of posts relevant to ε at the next time step T_{i+1}.

First we generate candidate keywords $\varkappa_c$ from F. The keyword generation step is discussed in the Proposed Solution below. For each candidate keyword, k, we assign a score that quantifies how good this keyword is to ε. In information retrieval, tf-idf, is a commonly used numerical statistic that is intended to reflect how important a word is to a document in a collection or corpus. In our case, the score we are trying to compute for each k as a function of S and F is a tf-idf like metric. It assigns weights to keywords in F according to their frequency of occurrence. If we let $|F_k|$ be the number of posts containing the keyword k, we can give a similar estimate as follows:

$$P(k|F) = \frac{|F_k|}{\sum_i |F_i|} \tag{1}$$

Similarly, the second component assigns a score of how important a keyword k is for all other events in ς except ε ($= \varepsilon^c$). Since we can not observe ς directly, we can use S and $\varkappa$ to estimate ε^c. Let us denote posts in S that do not contain any of the query keywords $\varkappa$ as S^o, then Similar to Equation 1:

$$P(k|S^o) = \frac{|S^o_k|}{\sum_i |S^o_i|} \tag{2}$$

[6] http://www.gdeltproject.org
[7] https://github.com/elastic/elasticsearch

Finally, in order to incorporate prior information of keywords and change the probabilities as we gain more evidence over time as the event unfolds, we apply Bayes' theorem in order to compute the likelihoods given the priors and our current estimates. In the following, we provide a walk through of the pseudo code of our proposed solution given in Algorithm 1.

Algorithm 1 Keyword Adaptation

Input: $keywords$ at time T_i, $FStream$, $Sstream$, θ, min_freq, P
Output: $keywords$ at time T_{i+1}

```
for k ∈ Fstream do
    if freq(k) > min_freq then
        add k to candidates        ▷ generate candidates
    end if
end for
for c ∈ candidates do
    estimate P(h)
    estimate P(o)
    update likelihood P(c)
    if P(c) > θ then
        add c to keywords
        update P
    end if
end for
return keywords
```

Proposed Solution. Let E denote a particular event that we are trying to track on Twitter, e.g., Berlin Attack. Initially, this event is described by the set of tweets returned from Twitter as a result of our search containing the first query keywords – seeds. If we analyze the set of keywords, i.e., hashtags and word n-grams, in the initial response, it contains predominantly the initial search terms and other potentially useful query terms for future searches. The question is how to decide, which of the new keywords are useful as potential query keywords.

The main ingredient to our solution is to consider the global context instead of dealing solely with the resulting social feeds of a particular event that we are tracking in order to update the query parameters, i.e., including possibly other major events that are happening at the same time. Our insight is that we can leverage the one percent Twitter sample to get a sample statistic of the global context. This public stream gives us a random set of tweets covering all major global events (given they are big enough). By analyzing simultaneously both the random one percent sample of the entire Twitter stream and a focused stream of tweets about the event we are interested in, we can make better decisions about which keywords pertain truly to the event we are trying to track and which just co-occur because of another event or are just noise. This will help us to avoid keywords coming from other events thereby mitigating keyword drift and identifying emerging keywords in our filter stream that are not contained in the query keywords. In practice people use hashtags and phrases to perform searches about unfolding events. In our implementation we use hashtags and word bi-grams as candidate keywords.

Suppose r is the hypothesis that a given keyword is relevant for an event and can be used as a search keyword. We can quantify how good this keyword is as a search term for the event E by computing the fraction of relevant tweets that contain this keyword, $P(r)$ as given in Equation 1. The intuition behind this is that, a keyword that generates more relevant tweets for an event when used as a query term should get a higher probability of being used as a search query than a keyword that does not bring as many relevant tweets.

For the first iteration, this can be initialized in such a way that we penalize globally most frequent keywords such as #rt, #ff etc. with low probabilities, seed query keywords with high probabilities and the rest of the keywords with some small uniform probability. We can leverage past collection of tweets from the one percent Twitter sample to estimate these probabilities.

Similarly if we let o be the hypothesis that a given keyword is relevant for all other events, other than the event E that we're tracking, then $P(o)$ as given in Equation 2 quantifies how good this keyword is as a search query for all other events but E.

Concretely, we estimate $P(r)$ using the **Filter Stream** as the fraction of tweets containing the query keyword in our search result. In the same way, we estimate $P(o)$ from the **Sample Stream**. In particular, we take the fraction of tweets containing the keyword by taking all tweets from the Sample Stream except those that contain the query keywords that are used to retrieve the tweets for the event E at the current time-step. Finally, we update these probabilities in order to make potentially useful keywords get higher probabilities and those keywords that are in the query set but are not relevant anymore receive small probabilities so that they can be dropped in subsequent queries. For a given keyword, after computing the likelihood, we compute the ratio of the likelihoods to decide if a given keyword should be included as a query keyword in the next iteration. We set a threshold, θ that defines this cut off. Algorithm 1 gives the concrete steps for the computation.

Evaluation Framework

One of the challenges in evaluating algorithms for real-time tracking of event on social media is setting up a simulation environment, where one can run experiments multiple times and in a reproducible manner. This is in contrast to ad hoc approaches where one has to anticipate and monitor the social media platform as a particular event happens and then run competing algorithms against such collection. To enable reproducible experiments, we created a "simulation" environment to re-create Twitter streams. In this section, we describe exactly how we simulate the Twitter stream for evaluating real-time adaptive crawlers.

Simulation Real-time Stream. In a typical social search problem, one prepares training and test set collections for the retrieval problem. Real-time adaptive retrieval systems are then evaluated on such setup for comparison. However, this setup is limited in the sense that one must have collected the social feeds corresponding to every event we care about as they happened beforehand. This makes reproducibility challenging. Instead of explicitly building a test collection that maintains relevant and non-relevant feeds, we create a simulation environment that can help us play back past events.

The Twitter Advanced Search is a rich query interface that exposes all Tweets through the complete Tweet index [8]. Access is done via search operations using query words (such as exact phrases, any key words, exclusion words or hashtags), people (e.g., tweets written to or from accounts and mentioning accounts), places and dates. Thus, a searcher can go back in time and filter feeds by combining these parameters, and by replaying, this essentially gives us the best way to simulate real Twitter streams.

Of course the Twitter Advanced Search is not exactly the same as the Twitter real-time stream. There are a couple of drawbacks, when using Advanced Search. First, this only gives back organic tweets, i.e., retweets are not included and some of the tweets might have been deleted. Second, there is no official API that supports this. We solve the latter problem by writing a wrapper around this interface to mimic the same way a user invokes the Twitter real-time stream through Twitter Public Stream, e.g., **Filter Stream**. Each crawler in our experiments gets its tweets from the end point we described earlier. Our implementation of this query interface is Publicly available [9] for others to reproduce our work and use it for similar social search tasks.

Optimizing the Environment. This simulation framework gives each algorithm the same end-point and is not constrained by the tweet collection procedure common in previous works, i.e., this approach is not prone to leakage of one's approach to generating the real-time stream for evaluation in the first place and an adaptive approach that may leverage techniques from the generating process. It cleanly separates the evaluation framework from competing adaptive algorithms.

In the experiments, a user initiates an algorithm to track a given event with a starting seed query, the algorithm uses the Twitter Advanced Search wrapper and its task is to modify the query as appropriate at different time windows as time goes.

In our experience, this could be slow if for instance a crawler suggests a generic term (with lots of tweets) at the early stage of the event. To overcome this, we perform two optimization measures. Early stopping and caching.

- Caching: to avoid repeating the same query to Twitter, we have a caching step, that indexes tweets and query parameters as the query progresses. Only when a query was not yet seen does the algorithm fire an actual interaction to the Twitter Advanced Search. This simple caching technique reduces the experimentation time from potentially several days to minutes.
- Early Stopping: For a given past event, a crawler e.g., can perform the following GET request to track the keyword 'berlin' from 19:20:00 to 19:24:59 on December 19 2016. Instead of going all the way from the the last minute of the day of December 19th to the beginning. We stop after retrieving tweets at 19:20:00.

EXPERIMENT

In this section, we will describe our ground-truth generation approach. Besides, we will disucss the evaluation protocol and results of our experiments to validate (i) the simulation environment to compare real-time adaptive search algorithms and (ii) how well our proposed algorithm performs compared to existing methods.

[8] https://blog.twitter.com/engineering/en_us/a/2014/building-a-complete-tweet-index.html
[9] https://github.com/asmelashteka/twitteradvancedsearch

Ground truth Data

In most previous work, the common way to evaluate different adaptive algorithms has been to run several competing algorithms and then annotate a subset of the returned tweets using crowd sourcing. This raises the question what if the algorithms miss out a large fraction of the event? In the following we propose a novel ground-truth generation approach. The idea is to leverage the flexible simulation frame work we described in the Evaluation Framework Section that allows us to look ahead and back. This gives an advantage that real-time adaptive crawlers do not have.

Approach. There are existing approaches, e.g., (McMinn et al. 2013), to build Twitter collections for events on Twitter. McMinn et al. proposed a methodology for generating Twitter corpus for event detection. This is however limited to a small number of tweets, up to 1000, per event. Our approach to building the ground-truth data mimics running a temporal adaptive crawler with relevance feedback of tweets from user annotations. Concretely, we start with seed keywords to collect the first tweets that describe the event. After this iteration, we generate candidate keywords of up to 400 keywords, a limitation imposed by Twitter, and label which keyword is relevant. In order to determine whether a given keyword is relevant or not, we look-ahead the tweets containing this keyword in the next iteration and assess it with the following two metrics.

1. Information Gain: What is the gain in terms of potential relevant tweets that are not covered by the query set in the current iteration? A potential keyword is considered a candidate keyword if it brings about at least a minimum number of tweets (e.g., 10) that wouldn't be generated with our current keywords.
2. Signal to Noise Ratio: Checks how many of the additional tweets from the candidate query, i.e., not covered by our current keywords, are relevant and how many are non-relevant? Here we use human annotators to inspect sample tweets and label the tweets as relevant or not. A potential keyword is included for the next iteration, if the relevance of the additional tweets meets a certain threshold, 70%.

Since no real-time adaptive search algorithm has the possibility to look-ahead into the future, we can guarantee that this is indeed the best choice a real-time adaptive algorithm can achieve.

Implementation. Concretely, we build a ground truth data for Berlin Attack. This has two desirable properties to test adaptive social search algorithms on. First, this is a big world wide event. This means, the algorithm has to deal with a big scale event. Second, there were other big global events happening on the same day. This creates a challenge for an algorithm to drift away from the event of interest.

Evaluation and Results

We compare the performance of our proposed approach with RKwA (Wang, Tokarchuk, Cuadrado, et al. 2013). Even though TAS (Sadri et al. 2016) would be another candidate, it is not easy to faithfully replicate as the results change drastically depending on the news article used to guide the search. RKwA and our system have the same setup in that they do not require any external dependency other than starting the search process with a set of seed query keywords. The experiment was to gather as many relevant tweets to the 2016 Berlin Attack as possible by modeling the query keyword dynamics of the event, i.e., by adding new relevant keywords and dropping obsolete ones. This is done every five minutes for the first two hours of the event. The ground truth data is constructed by manually simulating the adaptive crawler processes with the help of a crowd sourcing task. We used the seed keywords: #berlin, berlin christmas market, berlin weihnactsmarket. The ground-truth as well as the adaptive algorithms were run since: '2016-12-19 19:05:00' until: '2016-12-19 20:55:00.

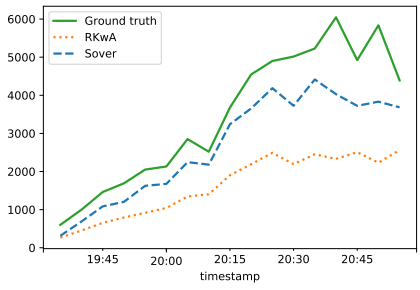
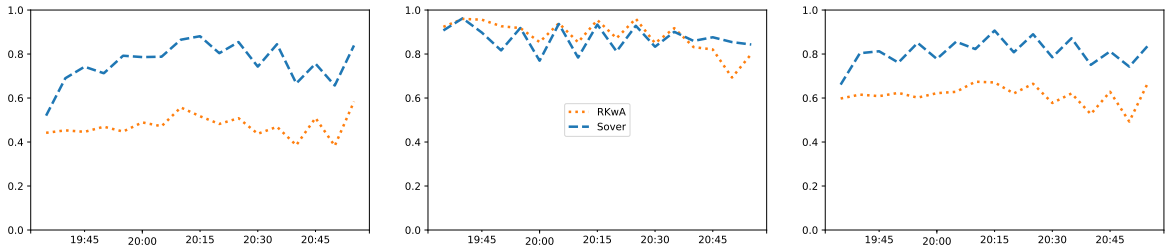


Figure 2. Number of relevant tweets gathered by (i) Sover! (ii) RkWA and (iii) the annotated ground-truth over the first two hours since the start of the event.

Relevance. This measures the total number of relevant tweets retrieved. In this case, the number of tweets that are about the Berlin Attack 2016. Figure 2 shows a comparison of the number of relevant tweets retrieved by the different algorithms. We see that **Sover!** performs better.



(a) Recall **(b) Precision** **(c) F1-score**

Figure 3. Evaluation of Real-time Adaptive Crawlers for Berlin Attack 2016 during the first two hours of the event.

Recall. is the fraction of relevant tweets that have been retrieved over the total amount of relevant tweets. Figure 3a shows that **Sover!** has significantly better recall than RKwA.

Precision. is the fraction of relevant tweets among the retrieved tweets. Figure 3b shows that **Sover!** achieves a higher recall without degrading on the precision.

F1-Score. is the weighted harmonic mean of precision and recall. Figure 3c shows that **Sover!** has overall better F1-Score than RKwA. It achieves a significant improvement with an average (over all five minute windows) F1 score of 0.81 for Sover! vs. 0.62 for RKwA.

Large-scale Crisis Simulation Exercise

Sover! was tested in a large-scale simulation exercise that was organized by the German Red Cross. The exercise was inspired by the 2013 European floods [10] crisis, in which Germany was affected. The main goal of the exercise was (1) to test communication methods, going beyond traditional means of communication and (2) to collect information from social media, mainly Twitter, using **Sover!** in order to enhance situational awareness. **Sover!** was particularly useful during the exercise to visualize the scale of the crisis through relevant posts that included images. This emphasizes the importance of visual content to enhance situational awareness. The keyword adaptation of **Sover!** was also useful. We observed that the keywords, e.g., #hochwasser ("flood") and #sturm ("storm") were added by the crawler automatically and reflected the exercise's scenario as the event was happening in the field.

CONCLUSION

In this work we presented the problem of real-time adaptive search. The challenges are: how to capture the evolution in the underlying vocabulary in order to dynamically change query keywords to track an unfolding event without adding too much noise. We proposed a method that solves this problem by leveraging simultaneously both a random sample of the Twitter stream and a focused stream about the event. The evaluation has shown that our method improves the performance of an adaptive Twitter crawler as compared to state-of-the-art methods. We also proposed a novel semi-automated ground-truth generation method in order to evaluate our proposed solution. This is also expected to bring the area forward by leading to more systematic approaches for evaluating adaptive crawling and social search technology. As a future work, we will explore how we can learn the ground-truth generation so that we can automate this process and apply it to similar events.

ACKNOWLEDGMENTS

We would like to thank Damianos P. Melidis, Negacy D. Hailu and the anonymous reviewers for their valuable feedback on the manuscript.

[10] https://en.wikipedia.org/wiki/2013_European_floods

REFERENCES

Abel, F., Hauff, C., Houben, G.-J., Stronkman, R., and Tao, K. (2012). "Twitcident: fighting fire with information from social web streams". In: *Proceedings of the 21st International Conference on World Wide Web*. ACM, pp. 305–308.

Castillo, C. (2016). *Big Crisis Data: Social Media in Disasters and Time-Critical Situations*. Cambridge University Press.

Chen, J., Cypher, A., Drews, C., and Nichols, J. (2013). "CrowdE: Filtering Tweets for Direct Customer Engagements." In: *ICWSM*. Citeseer.

Conover, M., Ratkiewicz, J., Francisco, M. R., Gonçalves, B., Menczer, F., and Flammini, A. (2011). "Political Polarization on Twitter." In: *ICWSM* 133, pp. 89–96.

Hadgu, A. T., Abualhaija, S., and Niederée, C. (2018). "Sover! Social Media Observer". In: *The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval*. ACM, pp. 1305–1308.

Hadgu, A. T., Garimella, K., and Weber, I. (2013). "Political hashtag hijacking in the US". In: *Proceedings of the 22nd International Conference on World Wide Web*. ACM, pp. 55–56.

Hadgu, A. T. and Jäschke, R. (2014). "Identifying and analyzing researchers on twitter". In: *Proceedings of the 2014 ACM conference on Web science*. ACM, pp. 23–32.

Magdy, W. (2013). "TweetMogaz: a news portal of tweets". In: *Proceedings of the 36th international ACM SIGIR conference on Research and development in information retrieval*. ACM, pp. 1095–1096.

Magdy, W. and Elsayed, T. (2014). "Adaptive Method for Following Dynamic Topics on Twitter." In: *ICWSM*.

Magdy, W. and Elsayed, T. (2016). "Unsupervised adaptive microblog filtering for broad dynamic topics". In: *Information Processing & Management* 52.4, pp. 513–528.

McCreadie, R., Macdonald, C., and Ounis, I. (2016). "EAIMS: Emergency Analysis Identification and Management System". In: *Proceedings of the 39th International ACM SIGIR conference on Research and Development in Information Retrieval*. ACM, pp. 1101–1104.

McMinn, A. J., Moshfeghi, Y., and Jose, J. M. (2013). "Building a Large-scale Corpus for Evaluating Event Detection on Twitter". In: *Proceedings of the 22Nd ACM International Conference on Information & Knowledge Management*. CIKM '13. San Francisco, California, USA: ACM, pp. 409–418.

Reuter, C., Ludwig, T., Kaufhold, M.-A., and Pipek, V. (2015). "XHELP: Design of a cross-platform social-media application to support volunteer moderators in disasters". In: *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, pp. 4093–4102.

Rogstadius, J., Vukovic, M., Teixeira, C., Kostakos, V., Karapanos, E., and Laredo, J. A. (2013). "CrisisTracker: Crowdsourced social media curation for disaster awareness". In: *IBM Journal of Research and Development* 57.5, pp. 4–1.

Sadri, M., Mehrotra, S., and Yu, Y. (2016). "Online Adaptive Topic Focused Tweet Acquisition". In: *Proceedings of the 25th ACM International on Conference on Information and Knowledge Management*. ACM, pp. 2353–2358.

Tumasjan, A., Sprenger, T. O., Sandner, P. G., and Welpe, I. M. (2010). "Predicting elections with twitter: What 140 characters reveal about political sentiment." In: *ICWSM* 10.1, pp. 178–185.

Wang, X., Tokarchuk, L., Cuadrado, F., and Poslad, S. (2013). "Exploiting hashtags for adaptive microblog crawling". In: *Proceedings of the 2013 ieee/acm international conference on advances in social networks analysis and mining*. ACM, pp. 311–315.

Wang, X., Tokarchuk, L., and Poslad, S. (2014). "Identifying relevant event content for real-time event detection". In: *Advances in Social Networks Analysis and Mining (ASONAM), 2014 IEEE/ACM International Conference on*. IEEE, pp. 395–398.

Track 9.

Universal Design of ICT in Emergency Management – *Identifying and Addressing ICT Challenges Faced by Elderly and People with Disabilities*

Chairs

Terje Gjøsæter, *Oslo Metropolitan University, Norway*

Jaziar Radianti, *University of Agder, Norway*

Weiqin Chen, *Oslo Metropolitan University, Norway*

Erion Elmasllari, *Fraunhofer Fit Institute Bonn, Germany*

CoRe and WiPe Papers – Universal Design of ICT in Emergency Management

Proceedings of the 16th ISCRAM Conference – València, Spain, May 2019

Zeno Franco, José J. González and José H. Canós, eds.

Life-Area Broadcasting System (LABS) for Normal and Emergency Cases by Using Easy Contents Management System and New Speaker Devices

Jun Sasaki
Iwate Prefectural University
jsasaki@iwate-pu.ac.jp
152-52 Sugo, Takizawa, Iwate, Japan

Taeko Maejima
Iwate Prefectural University
g031n146@s.iwate-pu.ac.jp
152-52 Sugo, Takizawa, Iwate, Japan

Shuang Li
Graduate School of Iwate Prefectural University
g236q005@s.iwate-pu.ac.jp
152-52 Sugo, Takizawa, Iwate, Japan

Yusuke Sato
Sato Watch Ltd.
info@iwate.tv
209 Hizume Koriyama, Shiwa, Iwate, Japan

Minoru Hiyama
Horonic Systems Ltd.
hiyama@holonic-systems.com
7-3 Kamihirasawababa, Shiwa, Iwate, Japan

Enrique Herrera-Viedma
University of Granada
viedma@decsai.ugr.es
Granada E-18071, Spain

ABSTRACT

The "community" has played an important role in enhancing the regional disaster management capabilities in Japan. This paper proposes a Life-Area Broadcasting System (LABS) for usual and emergency cases. In order to realize very simple and easy management of LABS, we developed the Easy Contents Management System (ECMS). By this system, people can obtain life-area information related to their life support, small events and accident news occurring at their living area not only in emergency cases but also in normal cases by voice, images and text. Further, we developed some new Speaker Devices for unfamiliar users of ICT devices such as elderly users. Those users can receive the service of LABS as like as a television or a radio broadcast terminal anytime and every day. In this paper, we describe the concept of LABS and introduces the developed new systems and devices.

Keywords

Broadcasting, Artificial Voice, Emergency Information, Community Construction, Universal Design

INTRODUCTION

March 11, 2011, the East Japan Great Disaster and Tsunami occurred, and the authors experienced a lot of things about the disaster response, people action and information systems to a large-scale disaster. Murayama et al. (2015, 2016), and other related papers reports the experience in detail. After, regarding to the emergency information system, Murayama and Sasaki, et al. translated the book of Hiltz et al. (2009) "Information systems for emergency management" and published it in Japanese.

Through the above experience, we noticed that there were important issues in the information system for emergency management. One is the problem of government work difficulty of decision making in the emergency management and the other is the "digital divide" problem. In the case of a large-scale disaster, non-government

(community) activity such as self-help and mutual aid are more required than public help by government. Because, when a large-scale disaster occurs, the response capacity of the local government is lacking. In order to promote non-governmental (community) activities, everyone in the area needs to share information immediately. For that, it is important to solve the "digital divide" problem. In this paper, at first we introduce conventional researches for the public support, and we describe the importance of the non-government (community) activity and propose an information system to solved the "digital divide" problem.

CONVENTIONAL RESEACHES

In emergency case, the ordinary government work changed into a completely different mode. Especially, an organization transformation, a quick decision making and communication with many related people are required. There are many papers on the emergency management systems, the decision making and communication methods in the case of emergency. For example, Turoff et al. (2004) designed the Dynamic Emergency Response Management Information System (DERMIS), Tu et al. (2009) proposed some working flows of transformation in a self-organizing team for emergency responses, and Gonzales et al. (2016) constructed a simulation model of disaster response. Paltta et al. (2012) described the communication gap in disaster management. Regarding to using Social Media, there are some papers. For example, Hilts et al. (2014) proposed to use of Social Media for U.S. Public Sector Emergency Manager and Abdllah et al. (2017) discussed about the issues on information spreading by Twitter in the case of the disaster. Regarding to the decision making in emergency, Cesta et al. (2014) proposed the training for the decision making in crisis based on plan adaptation. Further, Bernabé et al. (2018) also studied the impact of warning situations for decision making in transportation companies through social media. For decision making in medical area, Sasaki (2017) proposed the patient transport decision making in multiple hospitals in a large-scale disaster.

Above problems are related with the "public support" in an emergency case. Not only in an emergency case but also in normal case, the "public support" has a limitation because of the budget and human resource limitation. Therefore, voluntary evacuation by citizen is important for emergency, and it is necessary for all citizens to share disaster information promptly. If there is an information gap by "digital divide", the risk of response delay for a disaster will be serious.

IMPORTANCE OF COMMUNITY

Recently in the advanced countries including Japan, the aging society has progressed rapidly. In order to provide living in the familiar area continuously, the Japanese Government is constructing the Comprehensive Community Care System (CCCS), which is an integrated care system of medical, nursing, and health care, and including living support. In the CCCS, the "public support" provide the medical, nursing and health care service to required people. The living support (housekeeping, housework and shopping support, etc.) is difficult for the Government to provide as the "public support" because of the budget problem. Therefore, the living support by "mutual aid" as well as "self-help" is necessary by such as volunteers and NPOs (without official fund) so that elderly people can live the region comfortably in the future.

We expect the "mutual aid" to reduce the cost of "public support" in not only the normal case mentioned above but also in emergency cases. To activate the "mutual aid", we focused on the function of "community". MacIver (1917) defined the "community", which was not association or State but a free, natural, spiritual, common sense and voluntary association for people to make a comfortable social life. Matsumoto and Yatabe (2008) studied the determination factor to continue the disaster prevention activities was the sense of community. The sense of community means "affection for the region" and "the spirit of self-devotion for the region". They concluded the sense of community means the "humanity and love for mankind within local resident" and it is the most important factor towards the continuous disaster prevention activities. Tsuburaoka et al. (2014) reported the community information as the living information is important to reconstruct and to keep the function of "community". They also described the problems of "digital divide" and "non-digital citizens".

In this research, we focused on the "digital divide" and "non-digital citizens" to re-construct the "community", which means regional community for safety social life. Further, this paper proposes a new information system to realize re-construction of the community with solving the problems of "digital divide" and "non-digital citizens".

BLIND SPOT OF INFORMATION SOCIETY

The "community" has played an important role in enhancing the regional disaster management capabilities in Japan. In other to keep the "community" function, people has been using various regional information systems such as newspapers, radio broadcasting and a cable broadcasting, television and Social Network Systems (SNSs) by the Internet. Those systems are useful for getting and sharing more wide area information, but they are still too

large for a person to get more near information related to their life support, small events and accident news occurring at their living area. The reason why the media covers wider area than the living area is the facilities' cost and the maintenance cost of broadcasting system and other related media are still too large to construct and keep the life-area information systems and services for required areas. As a result, there is a blind spot between Internet and other information media.

Figure 1 shows the image of the blind spot between in Internet and other information media. Our proposal of Life Area Broadcasting System (LABS) aims to eliminate this blind spot. Here, the size of the Life Area means the area where even the elderly can walk, or the range of a school or kindergarten (about a radius of 2-3 km). In addition, the blind spot includes not only elderly people but also people who are not good at information manipulation such as visual impairment, hearing impairment and dementia. For those people, excessive information from the Internet will be a flood of information and they will reject all information from the Internet. As a result, the "digital divide" and "non-digital citizens" are appearing and leads to the collapse of the community in current information society.

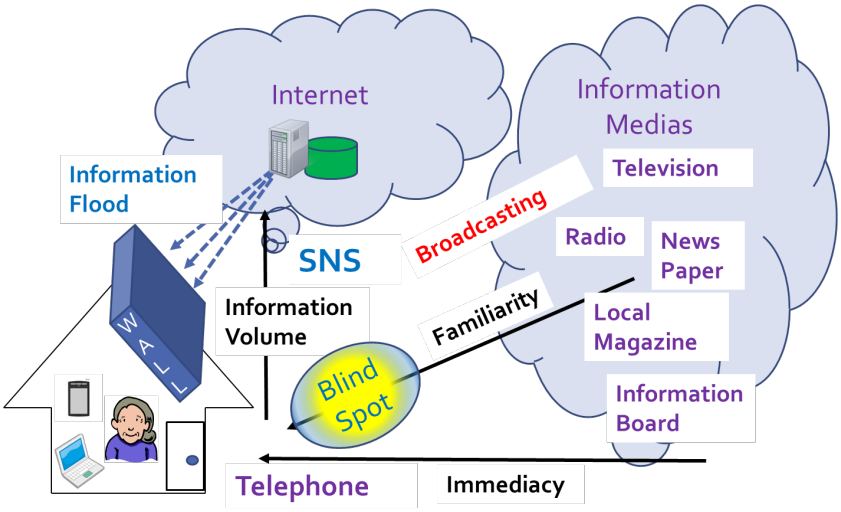


Figure 1. Blind Spot between Internet and other Information Media

CONCEPT OF LIFE-AREA BROADCASTING SYSTEM (LABS)

This paper proposes a Life-Area Broadcasting System (LABS) for usual and emergency cases. Figure 2 shows the concept of the proposed system of LABS. The feature of the system is as follows.

(1) **To provide both the formal information from Government Office such as emergency regional information and informal information from shops and community by the same system.** The conventional emergency system was for the government office and works in only emergency, but this does not connect to re-construct the community. Our proposal that the residents are receiving daily life information and sharing in the life area by LABS will connect the community re-construction. As a result, it leads to a high disaster responsible region.

(2) **To use our developed Easy Contents Management System (ECMS) described later in detail.** As the system distributes not only local government information but also private company or shop information, we consider that a non-profit organization (NPO) will manage the system. For this reason, we have developed an extremely easy-to-use contents management system so that even people without IT skills can manage the system.

(3) **To use new Speaker Device (SD) described later in detail.** In order to eliminate the "digital divide" and "non-digital citizens", we developed new speaker devices (SDs) for elderly people with weak hearing and vision and people who are not good at operating information terminals.

We also developed a smartphone application of the LABS for smartphone users. They can obtain the same service of LABS by using smartphone. The user can select the media of the information from voice, images, text (e-mail) and the combine of them. Smartphone users can directly obtain information from local government and stores not through LABS. Additionally by using the LABS, every users including non-smartphone users and smartphone

users can receive required life-area information every day as well as emergency information. By this system, all users in the same area can share the same information.

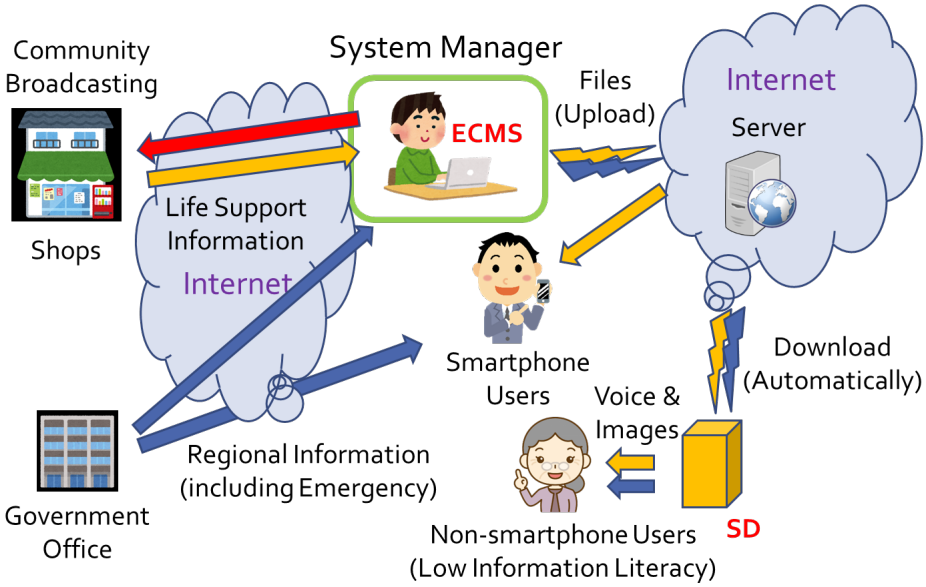


Figure 2. Concept of LABS

EASY CONTENTS MANAGEMENT SYSTEM (ECMS)

A feature of LABS is to use our developed Easy Contents Management System (ECMS). Figure 3 shows an example of the display of ECMS. The system manager of LABS for non-smartphone users uses this ECMS. The local government office sends their information directly to the smartphone users. The directly received information is still text (e-mail) and is not voice and images. Therefore, we developed an application which the smartphone users can receive the same information as that for non-smartphone users by the smartphone. The application provides the same information in voice or images or combine of them.

We divided contents of LABS into three classes, Emergency, Fixed Time and Optional Time. Each class has a specified time for the broadcast as follows,

- Emergency: one minute after the submit time,

- Fixed Time: pre-specified time in a day such as 7:00 am, 12:00 (noon), and 5:00 pm,

- Optional Time: depending on the contents.

For each classes, the system manager can select contents files and submit them to the system server. The contents files are voice files and image files. The system can send also text information as the image files. Recently, we can make the voice files from text files easily by using free software in the Internet. Further, the quality of the artificial voice becomes quite well, so we have not to use human resource to make the voice files. If the condition of the selected contents file is “open”, SD automatically downloads the file at the specified time. The user can delete the selected files and the user can change the condition of selected files from open to close anytime. There is an indicator of the number of downloads, the system manager can know the user’s terminal condition. As mentioned above, the ECMS has very easy human interface, so everyone can use it and everyone can be the system manager. There is no additional broadcasting facilities and it realize a very low cost broadcasting environment.

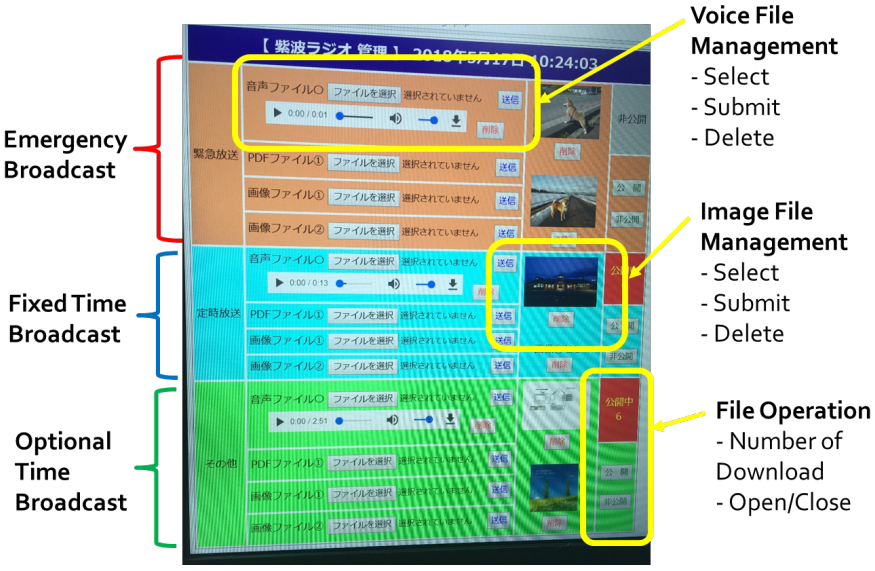


Figure 3. Display of ECMS

DEVELOPED SPEAKER DEVICES (SDs)

The other feature of LABS is to use our newly developed Speaker Devices (SDs). Figure 4 shows the photo of SDs. We developed two kinds of SD, one's name is "Radie" (Figure 4 (a)) which has a display and another's name is "Radita" (Figure 4 (b)) without display. We developed both of them using Raspberry Pi3. They can connect to Internet via WiFi and have file automatically download functions from the system server at the specified time mentioned above. After download the files, the SDs open the files and out the voice and image to the speaker and display (in the case of "Radie"). User can control the volume of the voice by turning the volume controller like a television or a radio. We developed the "Radita" (without display) by using the parts of conventional speaker terminals, which was for cable broadcasting. As a result, the "Radita" is very low cost and has a high-power speaker. This speaker is effective for the elderly with weak vision and slightly deaf ears.

In Japan, there are still many non-smartphone users. The most of them is elderly and needed the life-area information in the both of emergency and normal cases. We designed those devices for non-smartphone users. They require very easy use terminal like a television or a radio to get the life-area information. With this terminal, elderly and "digital divide" people can spend safely and convenient life because they can receive necessary life-area information automatically, and they not need to get information from themselves like the Internet.

Of course, as mentioned above, we also developed a smartphone application to receive and play LABS's contents by using regular smartphones. As a result, smartphone users and non-smartphone users are able to receive the LABS's service fairly. Namely, this will form a "universal designed" information community that no one will leave behind.

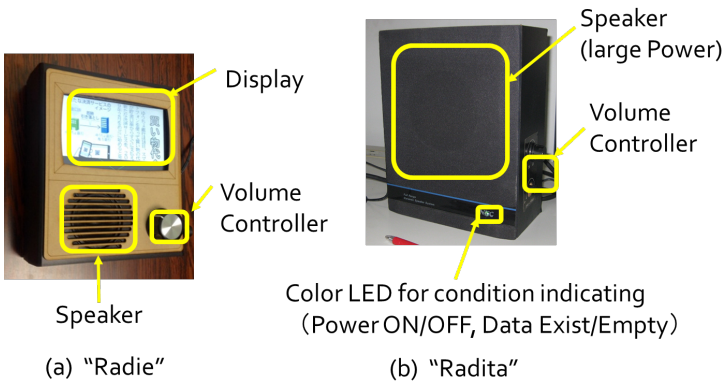


Figure 4. Developed Speaker Devices

CONCLUSION AND FUTURE WORKS

This paper proposed the concept of Life-Area Broadcasting System (LABS) for usual and emergency cases. To realize the LABS, we developed the Easy Contents Management System (ECMS) and some new Speaker Devices (SDs). We also developed a smartphone application to use the same service of LABS. By this system, every people including non-smartphone users and smartphone users can obtain life-area information related to their life support, small events and accident news occurring at their living area not only in emergency cases but also in normal cases by voice and images.

Using the LABS, we expect the re-construction of "community" by information sharing among the same life-area residents and increasing the communication opportunity at event in the life area. We believe the re-construction of "community" will connect to make a villages, a town and a city with high resilient to disasters.

The system introduced in this paper is still in the prototype stage. In the future, we have a plan that the actual elderly people and system managers use and evaluate the prototyped system. Then, improve the prototype system based on the evaluation results. After that, we have a plan of carrying out the field experiment on the effectiveness of the proposed LABS in Shiwa-town and Yahaba-town, Iwate Prefecture, Japan in 2019. Finally, we plan to establish an industry-government collaboration business model to operate this system and establish an NPO. By performing the continuous operation, we hope for the re-construction of "community", and the construction of a high disaster prevention, safety and secure region development.

ACKNOWLEDGMENTS

We would like to thank Mr. Seiji Sato, president of Sato Tax Accountant Corporation, I-O DATA Foundation and the financing of project TIN2016-75850-R from the FEDER Funds for support of this research.

REFERENCES

Y. Murayama, J. Sasaki and D. Nishioka (2016) Experiences in emergency response at the Great East Japan Earthquake and Tsunami, *Proc. 49th Hawaii International Conference on System Sciences (HICSS-49)*, pp.146-151.

Y. Murayama, J. Sasaki, et al. (2015) Survey on how people reacted at emergency response at the Great East Japan Earthquake and Tsunami, *The 12th International Conference on Information Systems for Crisis Response and Management(ISCRAM2015)*.

B. Van de Walle, M. Turoff and S.R. Hiltz eds. (2009) Information systems for emergency management, *M.E. Sharpe*.

J. Bernabé-Moreno, A. Tejeda-Lorente, C. Porcel, E. Herrera-Viedma (2018) Leveraging localized social media insights for early warning systems, *International Journal of Information Technology and Decision Making (IJITDM)* 17:1 (2018) 357-385.

M. Turoff, M. Chumer, et al. (2004) the Design of a Dynamic Emergency Response Management Information System (DERMIS), *Journal of Information Technology Theory and Application*, 5, 4, 1-35.

Y. Tu, W.Wang, et al. (2009) the essence of transformation in a self-organizing team, *Syst. Dyn. Rev*. 25, 135-159.

J. J. Gonzalez, L. Labaka et al. (2016) Insights from a Simulation Model of Disaster Response: Generalization and Action Points, *49th Hawai International Conference on System Sciences.*

P. Palttala, C. Boano, et al. (2012) Communication Gaps in Disaster Management: Perceptions by Experts from Governmental and Non-Governmental Organizations, *Journal of Contingencies and Crisis Management*, 20, 1,2-12.

S. R. Hilts, J. Kushma and L. Plotnick (2014) Use of Social Media by U.S. Public Sector Emergency Managers: Barriers and Wish Lists, *Proceedings of the 11th International ISCRAM Conference.*

N. A. Abdullah, D. Nishioka, et al. (2017) Why I Retweet? Exploring User's Perspective on Decision-Making of Information Spreading during Disasters, *50th Hawaii International Conference on System Sciences (HICSS-50)*.

A. Cesta, G. Cortellessa and R. D. Benedictis (2014) Training for crisis decision making- An approach based on plan adaptation, *Elsevier Knowledge-Based Systems*, 58, 98-112.

J. Sasaki (2017) A Proposal on Patient Transport Decision Making in Multiple Hospitals in a Large Scale Disaster, *IFIP AICT (Advances information and Communication), Information Technology in Disaster Risk Reduction, ITDRR 2016, Springer*.

R. M. MacIver (1917) Community, a sociological study: being an attempt to set out the nature and fundamental laws of social life.

M. Matsumoto and R. Yatabe (2008) Determinants that Motivate Continuous Disaster- Prevention Activity in Disaster- Stricken Area People (Japanese), *J. JSNDS*, 27-3, 319-330.

H. Tsuburaoka, A. Takei and T. Iwamoto (2014) Community Information as the Living Information - Rethinking of Community Information – (Japanese), *Tokyo University of Information Sciences*, 17, 2, 41-55.

J. Sasaki, K. Yamada, et al. (2009) Experiments of Life Monitoring System for Elderly People Living in Rural Areas, *HELTHINF 2009*, 430-433.

Y. Murayama, Y. Saito and D. Nishioka (2013) Trust Issues in Disaster Communications, *46th Hawaii International Conference on System Sciences*, 335-342.

Understanding Situational Disabilities and Situational Awareness in Disasters

Terje Gjøsæter
Oslo Metropolitan University, Norway
tergjo@oslomet.no

Jaziar Radianti
Centre for Integrated Emergency Management, University of Agder, Norway
jaziar.radianti@uia.no

Weiqin Chen
Oslo Metropolitan University, Norway
weiche@oslomet.no

ABSTRACT

In this paper, a scenario-based approach augmented with personas typically used in universal design and interactive design domains is used to illustrate the occurrence of situational disabilities in emergency situations, and to show how environmental factors can trigger these situational disabilities. With the help of personas representing selected archetypical characteristics and roles, the scenarios are further examined to show how these situational disabilities can affect the situational awareness of different stakeholders, not only in the command and control centers, but also first responders in the field as well as affected members of the public. This approach provides a better understanding of the importance of universal design of ICT for Emergency Management, not only for people with disabilities and the elderly, but for anyone.

Keywords

Situational Disabilities, Situational Awareness, Universal Design of ICT for Emergency Management.

INTRODUCTION

Attaining situational awareness (SA) is an important part of being able to take appropriate actions in catastrophic situations. It is equally important both for individual and closely related social groups in disaster events, as well as for all emergency responders that require shared or intergroup SA (Pogrebnyakov and Maldonado 2018; Seppänen et al. 2013). SA as a concept is introduced in the human factor domain in 1990s (Endsley 1995), especially in connection with the decision making and analyzing human errors and human performance (Endsley 2015). Scholars have explored, used and develop this concept into various domains in industrial automation, pilots, air traffic control and other high-risk activities in organizations or industries. The applicability of the use of SA concept in the area of emergency management has been explored, analyzed, used and demonstrated in some studies, e.g. for gaining common operational picture (Wolbers and Boersma 2013), development of information system decision support tool (Luokkala and Virrantaus 2014), emergency responder collaboration (Seppänen et al. 2013) and social media crisis communication (Pogrebnyakov and Maldonado 2018).

The concept of the perception – all human senses should work such as seeing, listening, smelling when it comes to establishing situational awareness in emergencies. One is supposed to use comprehension and cognitive capability to be able to understand and interpret all cues gathered by human sense, and to see the possible outcomes and to take actions. People also use tools and technologies to improve the human ability to sense and interpret the environmental cues that can also include either long or short numerical and written information and require a complex process before comprehending the information.

While we are aware of the importance of SA in disasters, the World Report on Disabilities states that the prevalence of disability is 15% and is increasing due to a global increase in chronic health in overall aging population. These catastrophic events not only increase the impairment incidence in certain regions but also may exacerbate medical conditions when disability-related health needs are not attended to appropriately. In the

disasters, people often need to be self-organized before the first responders come, and the ICT tools have been used to enhance the knowledge of the current situation. In this case, significant parts of the population have some kinds of disabilities that may prevent them from accessing relevant information and understanding quickly what happens, and what to do. Here, the role of the universal design of the ICT tools is important, as discussed by Radianti et al. (2017) and Gjøsæter et al. (2018). Also in the control room, universal design can play a role in supporting situational awareness (Gjøsæter and Radianti 2018).

In general, ICT is taking a bigger role in emergency management; and in the field, smart phones are becoming increasingly important as a first responder tells in his account of lessons learned during the hurricane Harvey[1]: *Smartphones are Extremely Powerful Tools*. "You can view maps, look up data and communicate effectively, as long as you keep your phone charged and functioning". However, we have to keep in mind that when introducing smart phones, we are also introducing the risk of encountering barriers to situational awareness through situational disabilities. The obvious cure for these barriers is Universal Design.

Universal Design concerns the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design. A prerequisite for Universal Design is accessibility. According to WAI/W3C, for the web, accessibility means that people with disabilities can perceive, understand, navigate, and interact with websites and tools, and that they can contribute equally without barriers (Bennett et al.2017; Gjøsæter et al. 2018). In other words, accessibility and usability for the broadest possible diversity of users.

Universal Design is said to be "Necessary for Some and Good for Everyone". This means that Universally Designed solutions that are absolutely necessary for some people, can also be very useful for others in certain situations or contexts. For example, subtitles on video is not only useful for people with a hearing impairment or an ear infection, but also for commuters watching the video on the bus with lots of traffic noise and other auditory disturbances, or in the library where they have to be quiet. In addition, people with a limited knowledge of the language spoken in the video may also benefit from the additional assistance of subtitles. These situations can be thought of as temporary or situational disabilities (SD).

In this paper we will examine how situational disabilities are particularly relevant in Emergency Management, not only for the general public but also for first responders and other stakeholders. We aim at understanding how SD affects SA in emergency situations, and based on this understanding we will argue for the importance of Universal Design of digital systems for SA in diverse contexts within Emergency Management, to mitigate the effects of SD on SA.

The SD issue is one of the unexplored areas with respect to the Universal Design of ICT for Emergency Management, and can be considered as the main contribution of this paper. While people with disabilities in emergency contexts are equally important, the potential invisibility of people experiencing SD sometimes means they do not receive the support required to cope with disaster contexts until those conditions become apparent to others. SD can occur both for the first responders and public who are affected by the disaster in general. Another contribution that is worth to mention is the use of *personas* for scenario analysis in emergencies, which would help better understanding of individual persons when it comes to disabilities and SD. Personas are imaginary characters representing user archetypes that are frequently used in research in interaction design and universal design of ICT, to illustrate how common groups of users might interact with systems (Pruitt and Grudin 2003).

This paper is organized into five sections. After this introduction, in the theoretical concepts and related work section, we introduce some important terms in this area such as disabilities, situational disabilities, and universal design. We also try to introduce briefly the concept of situational awareness, including the situational awareness barriers. Next, we present our research questions and explain briefly our method. In the analysis and discussion part, we answer our research questions and explain how disasters can trigger situational disabilities that in turn can reduce situational awareness. In the conclusion part, we summarize this paper, reveal some limitations and the future work.

THEORETICAL CONCEPTS AND RELATED WORK

Permanent, Temporary and Situational Disabilities

In this section, we will present some basic concepts used in this paper. What is disability? In 1980's disability is a personal attribute: "In the context of health experience, a disability is any restriction or lack of ability (resulting from an impairment) to perform an activity in the manner or within the range considered normal for a human

[1] https://www.itstactical.com/intellicom/mindset/lessons-learned-first-responder-hurricane-harvey/

being." –World Health Organization (WHO). However, today the WHO defines disability as context dependent, and no longer consider it just a health problem, but a complex interaction between features of person's body and features on the society where he or she lives, covering wider context:

- *Impairments*: a problem in a body structure;
- *Activity limitations*: a difficulty encountered by an individual in executing task or action;
- *Participation restrictions*: a problem experienced by an individual in involvement in life situations.

People are more aware on the issue of disabilities, and more efforts have been made to remove the difficulties face by people with disabilities, including social and environmental barriers, sometimes, it can occur that people are in the situation that cause auditory, cognitive, physical speech and visual impairment, which often referred to *situational disabilities*.

For example, a short-term injury or context affects the way people interact with the world around them, Likewise, when people are wearing a cast or ordering dinner in a foreign country. People's ability can change as they move through different environment. Noisy sound background can reduce someone's hearing ability. New parents often do their tasks one-handed. A strong bright light when driving a car can cause visual impairment. An overwhelming day can cause sensory overload. What's possible, safe, and appropriate is constantly changing (Shum et al. 2016). To understand these situational disabilities, temporary disabilities and permanent disabilities, we cite the Persona Spectrum that can be used to understand the inclusive design as seen in Table 1.

Table 1. The Persona spectrum with respect to permanent, temporary and situational disabilities (based on Shum et al, 2016).

	Permanent	Temporary	Situational
Touch	One arm	Arm injury	New parent with a child on the arm
See	Blind	Cataract	Distracted driver
Hear	Deaf	Ear infection	Bartender in a noisy bar
Speak	Non-verbal	Laryngitis	Heavy accent that is difficult to understand

Using this "situational disabilities" perspective, we obtain a new understanding that many people may have experienced a sort of situational disabilities. When situational disability happens, the situational awareness may reduce significantly. For instance, in a noisy crowd or due to ear infection, the announcement of the likely evacuation due to fire may not be heard. In a strong light, or driving situation, one may not be able to read or see the alert message, e.g. on the likely flash flood ahead.

Situational Awareness (SA)

SA is essential in an emergency situation, for the general public affected by the emergency as well as for first responders and decision makers. In the literature, SA developed on an individual level and on a team level to comprehend a crisis situation. In addition, there are numerous definitions of SA derived from different application areas such as military, aviation, air traffic control, large-systems operations, navy, and psychology. Consequently, SA has been defined in different ways, for example "the results of a dynamic process of perceiving and comprehending events in one's environment may change and permitting predictions as to what the outcomes will be in terms of performing one's mission. In effect, it is a development of a dynamic mental model of one's environment" (Nofi 2000). Endsley (1995) proposes a three-level model to define SA. It is referred as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". These three SA concepts i.e. perception, comprehension and projection have been referred as Level 1, 2 and 3 SA respectively. When crisis management stakeholders and response team cooperate together in responding crisis, team SA would be equally important as the individual SA. However, the coordination would be very crucial as each team member may have a specific set of SA elements depending upon each member's responsibility in the team (Endsley, 1995).

Poor situational awareness has been considered as important factor that lead into poor team SA (Kaber and Endsley 1998; Stanton et al. 2001) such as failure to detect critical cues regarding the state of the system; or failure to interpret the meaning of information from monitoring technology. It can also occur due to misunderstanding of individual task and responsibilities, to communicate with other teams and with individual within other teams.

However, there are several factors that can affect the SA. Some of the factors that can affect SA are called *SA demons*. Eight categories of SA demons have been identified and each presents its own set of challenges to

maintaining SA (Bhatt and Güsgen 2012).

- *Attentional narrowing* - Humans are easily affected by attentional narrowing, systems need to support multitasking across multiple goals and decisions.
- *Requisite memory trap* – Humans tend to have limitation to hold short term memory and information and therefore systems should not rely on short term memory that is easily disrupted.
- *Workload, fatigue and other stressors* – Humans' capabilities decrease when having fatigue, stress and high workload. These factors all act to reduce already limited working memory and disrupt information acquisition.
- *Data overload* - The volume and rate of change of data in many systems can run faster than operators' abilities to keep up with it
- *Misplaced salience* - The overuse of prominent visual features such as bright colors and flashing lights overwhelm and misdirect operators' attention.
- *Complexity creep* – The more complex the system, the harder it is for operators to develop accurate situation comprehension and projection.
- *Errant mental models* – Humans tends to misinterpret data based on how a different part of the system works Without good mental models of how a system operates being triggered.
- *Out-of-the-loop syndrome* - Highly automated systems can leave operators with low awareness of the state of the system.

While the analysis of these situational awareness demons has helped us to understand what kinds of "disabilities" could happen to people in a stress condition, the discussions of these SA demons has been limited to those who work as operators in control rooms. Endsley (1995), e.g. has worked extensively on SA behaviors derived from very specific flight operations. While in this paper, we argue that in disaster situations, the SA is actually required for the general public (who receive lifesaving information), responders (who conduct lifesaving actions in a coordinated manner, uses various tools and technologies in the field to support the response activities), and the operators and decision makers in the command and control room (who collect information, use technologies and provide the decision supports). However, the discussion on SA of these three groups of important parties in crisis management, never fully discussed in depth, and especially their barriers to SA. We would like to portray the SA issue from the perspective of situational disabilities and eventually from the lens of the universal design.

Situational Awareness and Situational Disabilities

The Persona Spectrum shown in Table 1 have depicted that "disabilities" can also occur to everyone who is unnecessarily a part of the vulnerable groups due to specific, situational or temporary conditions. However, the effects of such situational disabilities may result in the same effects as those who are actually having disabilities. In other words, inclusiveness of crisis management should be understood in both cases: the vulnerable groups and situational disabilities as their abilities to survive disasters. Note that there are variations on the use of the term "vulnerable groups". Généreux et al. (2018) use "high risk population" to refer to "anyone who has functional limitations related to communication, housing, awareness, mobility/transportation, psychosocial factors, self-care/daily tasks, and safety/security that may put them at higher risk of negative impacts when an emergency or disaster occurs". We use the "vulnerable group" in the same meaning as the "high risk population". However, in this paper, we argue that the vulnerability goes beyond the "high risk population" only, as it can occur to anyone.

Indeed, we are aware of a recent concept of disaster resilience that has encouraged the all-of-society approach to survive disasters, i.e. by enhancing the capacity of individual, citizens and society at large to cope with, resist and respond to disaster. Généreux et al. (2018) propose a community resilience framework of the vulnerable groups, while O'Sullivan et al. (2017) use the stroke patients as a case study of a vulnerable group to derive keys for household resilience, which cover the social, physical, energy and personal characteristics as keys. Assistive devices such as lifeline personal alarms, lanyard/wristbands and mobile phones are the tool examples for reducing the individual vulnerabilities. While we acknowledge the efforts to increase disaster resilience to the household unit, even well-prepared plans can sometime fail, because of failing to understand the potential barriers when using assistive tools and the role of situational disabilities, where a person may be unable to operate the technologies that they use on a routine basis.

Previous studies have tried to explore barriers encountered by the vulnerable groups in disaster situations. For instance, Sullivan and Häkkinen (2006) argue that the historical evidence has documented significant numbers of population affected by disasters fail to take actions upon warnings of imminent disaster. People with disabilities become disaster victims due to trapped in a high-rise structure during the fire, crushed in collapsing structures during an earthquake, swept away in a tsunami or drowned in a hurricane storm surge are all examples how people

with disabilities can encounter barriers of receiving critical lifesaving information or mobility problems. Häkkinen and Sullivan (2007) analyze some assistive technologies to improve the effectiveness of the communication of warning and critical information, especially with respect to the speech-based delivery of critical information. Specifically, the authors suggest the accessible Web content and Digital Talking Books as means to convey urgent, critical messages. The authors also highlight the importance of communication that also applied for multi-lingual and multi-cultural environments which in our point of view can also be categorized as a form of situational disabilities.

On one hand, the efforts of linking the universal design with disability issue and situational awareness are evident such as in Häkkinen and Sullivan (2007) work, but the fact the "disabilities" can occur to anyone are missing in the current literature. For example, what factors that can lead into these situational disabilities, and why it is equally important to understand both vulnerable groups and situational disabilities. Would the SA demons' valid in the crisis management context, and especially when involving people with disabilities and situational disabilities? In the following, we will examine how emergency situations can cause situational disabilities which in turn can trigger SA demons.

RESEARCH QUESTIONS AND METHODS

Based on the identified issues above concerning situational awareness as it is affected by situational disabilities, we have defined the following research questions:

- RQ1: What kinds of situational disabilities will people typically experience (physically and mentally) in disaster situations?
- RQ2: How do these situational disabilities affect situational awareness in disaster situations?

We have applied a scenario-based analysis method to examine these research questions through different disaster scenarios and discuss how different categories of people can be affected by situational disabilities in these scenarios. The scenario-based analysis method is frequently used in software engineering to elicit requirements, and is here adapted for eliciting examples of SD and their effect on SA demons. We have enhanced the scenarios with simplified imaginary individuals, or *personas*. In addition to an invented name, personas will have relevant characteristics typical for an important group of users, and might also be supplied with less relevant information and a semi-realistic backstory to assist in making the scenarios more realistic. The personas were created based on literature analysis through which we have identified the main stakeholders, their activities and challenges in emergency situations.

SCENARIOS, PERSONAS AND ANALYSIS

RQ1: Situational Disabilities in Disaster Situations

To examine the occurrence of situational abilities in disaster situations, we provide some typical imaginary scenarios. These scenarios are organized from three categories in terms of stakeholders, actions and potential situational disabilities. In both scenarios, the stakeholders are represented by personas from four groups of stakeholders;

1. local members of the general public
2. non-local members of the general public,
3. first responders,
4. control room personnel.

Scenario 1: Earthquake in a city.

Earthquakes can contribute to triggering several situational disabilities, as the following imaginary scenario will illustrate.

In Reykjavik on Iceland, a strong earthquake strikes one day in late February, around 2AM in the morning.

Martin lives in a small 12th floor apartment in downtown Reykjavik. He is used to evacuating during fire drills, but this is different. He fights the panic as he awakes, puts on some warm clothes, grabs his smart phone, locks his apartment and quickly walks down the stairs among a crowd of other people, who are equally stressed and worried, and making a lot of noise. When he finally comes out of the building, he sees that some of the surrounding buildings have partly collapsed. He tries to check the news using his smartphone to find out more information

about what has happened, but although he is wearing warm clothes, his hands are still shaking from the cold combined with his high level of stress, so he has difficulty navigating the news. All the noise from the crowd and the still shaking ground is making it even harder to focus. His neighbor Alejandra is recently arrived to Iceland from Mexico to work on her PhD. In a panic, she didn't think of taking warm clothes with her as she left the apartment. Fortunately, she remembered to grab her smartphone on the way out. She is now very cold, and the noise makes it even more difficult to concentrate on finding safe shelter. There is a woman wearing a Red Cross uniform coming towards her, but she doesn't understand what she is saying. The woman is Anna. She has been a volunteer for Red Cross for several years, but this is the first big emergency she has been a part of. Although she has had a lot of training, she still feels unprepared for the challenge of finding, prioritizing and helping victims in such a disaster. Also, the emergency communication equipment is unfamiliar to her, and she is trying to remember the correct channel and how to communicate effectively. Olav works in the emergency control room communicating closely with different first responders in the field, including Anna. He is surrounded by monitors with warning messages and audible alarms. He is very stressed and overwhelmed by all the reports of collapsed buildings in his area of responsibility, and have a really hard time choosing how to distribute resources, gravely aware that his decisions can have severe consequences.

Stakeholders, actions and potential situational disabilities:

- Local member of the general public in the process of evacuating from the location of an earthquake ("Martin").
    - The person is trying to get an overview of the situation through his smartphone.
    - The person is trying to submit information about the situation to the local authorities through his smartphone.
    - Situational factors: stress, fear/panic (countered by some basic training in emergency response through earthquake drills), shaking ground, movement (running), crowds, noise.
    - Situational disability risks: hearing (noise from the crowd, collapsing buildings), dexterity (own and ground movement), cognitive (stress, panic).
    - Potential consequences: Cannot adequately use the smart phone because of SD.

- Recent immigrant in the process of evacuating from the location of an earthquake ("Alejandra").
    - The person is trying to get an overview of the situation through her smartphone.
    - The person is trying to use smartphone for translating some of the messages and information provided.
    - Situational factors: stress, fear/panic, shaking ground, movement (running), crowds, noise, lack of training in evacuation.
    - Situational disability risks: hearing (noise from the crowd, collapsing buildings), dexterity (own and ground movement), cognitive (stress, panic, language barrier).
    - Potential consequences: Cannot adequately use the smart phone because of SD. Do not understand messages and orders given, with potentially fatal consequences.

- First responder in the field during an earthquake ("Anna").
    - The person is trying help where it is most needed, and therefore needs to achieve SA through observation as well as communication equipment connecting them to the central control.
    - Situational factors: stress, crowds, noise, cognitive overload trying to prioritize victims. Ground shaking.
    - Situational disability risks: hearing (noise from victims, collapsing building), dexterity (own and ground movement), cognitive (stress).
    - Potential consequences: Cannot adequately use the mobile communication equipment because of SD. Risk of wrong decisions because of communication problems.

- Control room personnel during earthquake ("Olav").
    - The person is trying to continuously perform observation, analysis, decision-making, communicating orders.
    - Situational factors: Information overload through multiple information channels, stress from life-and-death-affecting decision making.
    - Situational disability risk: cognitive (stress).
    - Potential consequences: error in judgement caused by information overload.

Scenario 2: Fire in a multi-floor shopping mall.

Fire can contribute to triggering several situational disabilities, as the following scenario will illustrate.

Just before closing time, a fire breaks out in the "Galleriet" shopping mall in Bergen, Norway. It was caused by an accident in the kitchen of one of the ground floor snack bars. The fire alarm goes off, and evacuation begins. Bill is an American tourist on a one day visit from a cruise ship. He is a bit lost, but finds a map on the wall. To his dismay, the information is only in Norwegian. He tries using google translate to translate the text, but because of stress he gives up and rather follows the crowd to the nearest exit. Janne is on the top floor, and she is trying to use a smartphone indoor map of the mall to find the way to the nearest emergency exit. Along the way, she sees a person in a wheelchair who is unable to evacuate without assistance, and he is too heavy for her to carry. She sends a message about the trapped person to the local fire department using twitter, since the noise from the fire alarm is too loud for being able to communicate using the emergency phone number. Nils in the fire department control center is overwhelmed by all the messages about the rapid development of the fire, but sees the tweet from Janne, calls Petter the fire fighter over the emergency communication network, and Petter makes his way to the top floor and is able to help the trapped person out of the burning building.

Stakeholders, actions and potential situational disabilities:

- Local member of the general public in the process of evacuating the building ("Janne").
  - The person is trying to locate emergency exits through their smartphone indoor map.
  - The person is trying to notify the emergency responders about a person in a wheelchair trapped on the top floor by sending a tweet to the fire department through their smartphone.
  - Situational factors: stress, fear/panic (countered to some degree by regular training in building evacuation through fire drills), smoke, crowds, moving fast, noise (loud fire alarm).
  - Situational disability risks: vision (smoke in the eyes), hearing (loud alarm), dexterity (walking/running), cognitive (stress/panic).
  - Potential consequences: Cannot adequately use the smart phone because of SD.

- Tourist in the process of evacuating the building ("Bill").
  - The person is trying to use the smartphone to translate evacuation map text.
  - Situational factors: stress, fear/panic, smoke, crowds, moving fast, noise (loud fire alarm), lack of training in building evacuation.
  - Situational disability risks: vision (smoke in the eyes), hearing (loud alarm), dexterity (walking/running), cognitive (stress/panic, language barrier)
  - Potential consequences: Cannot adequately use the smart phone because of SD. Do not understand messages and orders given, with potentially fatal consequences.

- First responder in the fire ("Petter").
  - The person is trying help where it is most needed, and therefore needs to achieve SA through observation as well as communication equipment connecting them to the central control.
  - Situational factors: stress, crowds, noise, cognitive overload trying to prioritize victims. Smoke, heat.
  - Situational disability risks: vision (smoke), hearing (alarm noise), dexterity (fast movement, bulky protective equipment), cognitive (stress)
  - Potential consequences: Cannot adequately use the mobile communication equipment because of SD. Risk of wrong decisions because of communication problems.

- Command and control center's personnel during fire ("Nils").
  - The person is trying to continuously perform observation, analysis, decision-making, communicating orders
  - Situational factors: Information overload through multiple information channels, stress from life-and-death-affecting decision making.
  - Situational disability risks: cognitive (stress).
  - Potential consequences: error in judgement caused by information overload.

RQ2: How SD can Feed the Demons of SA in Disaster Situations

The following overview shows which SD will feed the different SA demons (Bhatt and Güsgen 2012). First, we adapt the Persona Spectrum from Table 1 (Microsoft, 2016) in Table 2 (for issues in the field) and Table 3 (issues in the control room) with disaster-specific situational disabilities, as well as several additional types of disabilities including cognitive and dexterity/fine-motorics. For clarity, we divide the tables into two types of disabilities; sensing and perception-related, and action-related.

Table 2. Situational Disability Triggers in the field

		Situational Disability Triggers
Perceive		
	Touch	Hot/cold/wet/protective gear leading to loss of feeling
	Vision	Dust and/or smoke
	Hearing	Noise/alarms
	Cognitive (understand, interpret)	Language barriers, information overload
Action		
	Speaking	Dust and/or smoke in the throat, language barriers
	Moving	Protective gear, crowds, panic
	Fine-motorics /dexterity	Panic/stress, protective gear
	Cognitive (plan – act)	Information overload, confusion (wrong communication channel, forgetting protocol)

Situational awareness demons encountered in the field (effects that are not among the established demons are shown in parenthesis, while the situational awareness demons are marked with bold italic):

- Touch SD: (Not detecting haptic feedback/vibration).
- Vision SD: ***Data overload***; ***Misplaced Salience***.
- Hearing SD: ***Data overload***; ***Misplaced Salience***.
- Cognitive (understanding) SD: ***Attentional narrowing***; ***Requisite memory trap***; ***Workload, fatigue and other stressors***.
- Speaking SD: (Language barrier, too much noise to be heard).
- Moving SD: (Blocked, slowed or redirected movement),
- Dexterity SD: (Barrier for access to ICT-based SA tools).
- Cognitive (act) SD: ***Attentional narrowing***, ***Requisite memory trap***, ***Workload, fatigue and other stressors***.

Table 3. Situational Disability Triggers in the Control Room

		Situational Disability Triggers
Perceive		
	Touch	
	Vision	Many screens and blinking lights
	Hearing	Noise/alarms
	Cognitive (understand, interpret)	Information overload
Action		
	Speaking	
	Moving	
	Fine-motorics /dexterity	Stress
	Cognitive (plan – act)	Information overload, confusion (wrong communication channel, forgetting protocol)

In the control room scenarios, the following situational disabilities map to the following SA demons (effects that

are not among the established demons are shown in parenthesis, while the situational awareness demons are marked with bold italic):

- Vision SD: ***Data overload***; ***Misplaced Salience***.
- Hearing SD: ***Data overload***; ***Misplaced Salience***.
- Cognitive (understanding) SD: ***Attentional narrowing***, ***Requisite memory trap***, ***Workload, fatigue and other stressors***; ***Data overload***; ***Misplaced Salience***.
- Dexterity SD: (Stress affecting ability to manipulate control room equipment).
- Cognitive (act) SD: ***Attentional narrowing***; ***Requisite memory trap***; ***Workload, fatigue and other stressors***.

We notice that several of the effects are outside the scope of the demons of situational awareness, in particular when it comes to situational disabilities triggered in the field. Thus, the situational disabilities are not aligning well with the demons of SA, beyond the control room parts of the scenarios above. This makes sense since the demons of SA were defined in the context of control room SA.

From this research, we find that the demons of SA are not sufficiently general to cover the issues met by the general public and first responders. They cover mainly cognitive overload in control room situations, but not so much situations in the field with mobile equipment. This is a major issue that will be investigated in future work.

CONCLUSIONS AND FUTURE WORK

In this paper we adopted scenario-based analysis with simplified personas to identify situational disabilities among stakeholders in disaster situations and the demons of situation awareness. We have found that the Demons of SA (Bhatt and Güsgen 2012) are not adequately covering the issues of loss of SA caused by situational disabilities for major groups of stakeholders in typical disaster scenarios, such as the general public and first responders. Further studies should be performed to examine this issue in more details and provide a more complete picture of the demons of situation awareness, and we are currently working on extending the "Demons of SA" so that they cover other contexts as well.

In our scenarios, we see that ICT in addition to providing opportunities for increased situational awareness, can also introduce barriers to situational awareness through situational disabilities which can further hinder effective actions. It also becomes clear that not only obviously vulnerable groups like the elderly and people with disabilities needs special consideration when designing ICT tools for EM. We wish to highlight that Universal Design of ICT tools for emergency management can play an important role in removing these barriers and make the tools usable for a broader range of users, even those affected by situational disabilities (Gjøsæter and Radianti 2018; Gjøsæter et al. 2018; Radianti et al. 2017). Further research should focus on how Universal Design principles and guidelines can be used in the development process of ICT tools for Emergency Management, and a process model to illustrate the use of universal design principles in the design of ICT systems to support SA is part of ongoing work. This model is built upon the process model for information system of SA (Luokkala and Virrantaus, 2014) and demonstrate the adoption of UD in the whole process of ICT systems for SA.

REFERENCES

Bennett, DeeDee, Brenda D Phillips, and Elizabeth Davis. 2017. 'The future of accessibility in disaster conditions: How wireless technologies will transform the life cycle of emergency management', *Futures*, 87: 122-32.

Bhatt, Mehul, and Hans Werner Güsgen. 2012. "Situational awareness for assistive technologies." In. Amsterdam: IOS Press.

Endsley, Mica R. 2015. 'Situation awareness: operationally necessary and scientifically grounded', *Cognition, Technology & Work*, 17: 163-67.

Endsley, Mr. 1995. 'Toward a theory of situation awareness in dynamic systems: Situation awareness', *Human factors*, 37: 32-64.

Généreux, Mélissa, Geneviève Petit, Mathieu Roy, Danielle Maltais, and Tracey O'Sullivan. 2018. 'The "Lac-Mégantic tragedy" seen through the lens of the EnRiCH Community Resilience Framework for High-Risk Populations', *Canadian Journal of Public Health*, 109: 261-67.

Gjøsæter, Terje, and Jaziar Radianti. 2018. "Evaluating Accessibility and Usability of an Experimental Situational Awareness Room." In *AHFE2018*, 216-28. Springer International Publishing.

Gjøsæter, Terje, Jaziar Radianti, and Weiqin Chen. 2018. "Universal Design of ICT for Emergency Management - A Systematic Literature Review and Research Agenda." In *International Conference on*

Universal Access in Human-Computer Interaction, 63-74. Las Vegas, USA: Springer International Publishing.

Häkkinen, MT, and Helen T Sullivan. 2007. "Effective communication of warnings and critical information: application of accessible design methods to auditory warnings." In *Proceedings of Information Systems for Crisis Response and Management Conference (ISCRAM), Delft, Netherlands (May 2007)*.

Kaber, David B, and Mica R Endsley. 1998. 'Team situation awareness for process control safety and performance', *Process Safety Progress*, 17: 43-48.

Luokkala, Pekka, and Kirsi Virrantaus. 2014. 'Developing information systems to support situational awareness and interaction in time-pressuring crisis situations', *Safety Science*, 63: 191-203.

Nofi, Albert A. 2000. "Defining and measuring shared situational awareness." In.: CENTER FOR NAVAL ANALYSES ALEXANDRIA VA.

O'Sullivan, Tracey L, Christine Fahim, and Elizabeth Gagnon. 2017. 'Asset Literacy Following Stroke: Implications for Disaster Resilience', *Disaster medicine and public health preparedness*, 12: 312-20.

Pogrebnyakov, Nicolai, and Edgar Maldonado. 2018. 'Didn't roger that: Social media message complexity and situational awareness of emergency responders', *International Journal of Information Management*, 40: 166-74.

Pruitt, John, and Jonathan Grudin. 2003. "Personas: practice and theory." In *Proceedings of the 2003 conference on Designing for user experiences*, 1-15. San Francisco, California: ACM.

Radianti, J, T Gjøsæter, and W Chen. 2017. "Universal design of information sharing tools for disaster risk reduction." In *Second IFIP Conference on Information Technology in Disaster Risk Reduction, Sofia-Bulgaria*.

Seppänen, H., J. Mäkelä, P. Luokkala, and K. Virrantaus. 2013. 'Developing shared situational awareness for emergency management', *Safety Science*, 55: 1-9.

Shum, Albert, Kat Holmes, Kris Woolery, Margaret Price, Doug Kim, Elena Dvorkina, Derek Dietrich-Muller, Nathan Kile, Sarah Morris, Joyce Chou, and Sogol Malekzadeh. 2016. "Inclusive: A Microsoft Design Toolkit." In.: Microsoft.

Stanton, Neville A, Peter RG Chambers, and J Piggott. 2001. 'Situational awareness and safety', *Safety Science*, 39: 189-204.

Sullivan, Helen T, and Markku T Häkkinen. 2006. "Disaster preparedness for vulnerable populations: determining effective strategies for communicating risk, warning, and response." In *Third annual Magrann research conference at Rutgers University*, 21-04.

Wolbers, Jeroen, and Kees Boersma. 2013. 'The Common Operational Picture as Collective Sensemaking', *Journal of Contingencies and Crisis Management*, 21: 186-99.

Track 10.

Knowledge, Semantics and AI for Risk and Crisis Management

Chairs

Hedi Karray, *INP-ENIT, University of Toulouse, France*

Antonio De Nicola, *ENEA, Italy*

Nada Matta, *Université de Technologie de Troyes, France*

An Automatic Approach to Qualitative Risk Assessment in Metropolitan Areas

Denis Barcaroli
ENEA, Italy
denis.barcaroli@gmail.com

Alex Coletti
Booz Allen Hamilton
alexscoletti@gmail.com

Antonio De Nicola
ENEA, Italy
antonio.denicola@enea.it

Antonio Di Pietro
ENEA, Italy
antonio.dipietro@enea.it

Luigi La Porta
ENEA, Italy
luigi.laporta@enea.it

Maurizio Pollino
ENEA, Italy
maurizio.pollino@enea.it

Vittorio Rosato
ENEA, Italy
vittorio.rosato@enea.it

Giordano Vicoli
ENEA, Italy
giordano.vicoli@enea.it

Maria Luisa Villani
ENEA, Italy
marialuisa.villani@enea.it

Enrico Zavagnini
ENEA, Italy
enr1996@live.it

ABSTRACT

Risk assessment aims at improving prevention and preparedness phases of the crisis management lifecycle. Qualitative risk assessment of a system is important for risks identification and analysis by the various stakeholders and often requires multi-disciplinary knowledge. We present an automatic approach to qualitative risk assessment in metropolitan areas using semantic techniques. In particular, users are provided with a computational support to identify and prioritize by relevance risks of city services, through generation of semantic descriptions of risk situations. This approach is enabled by a software system consisting of: TERMINUS, a domain ontology representing city knowledge; WS-CREAM, a web service implementing risk identification and ranking functions; and CIPCast, a GIS-based Decision Support System with functions of risk forecast due to natural hazards. Finally we present the results of a preliminary validation of the generated risks concerning some points of interest in two different areas of the city of Rome.

Keywords

Risk assessment, geographic information system, conceptual modeling, ontology, computational creativity.

INTRODUCTION

Recent disasters in urban areas have caused an increasing interest in risk assessment. Knowing the possible risks for a specific area could increase the level of prevention and preparedness of a community to a crisis. Two types of approaches are commonly used for risk assessment of systems. Qualitative risk assessment involves system stakeholders to identify risk situations and prioritize them. Quantitative risk assessment, which may follow the qualitative approach, is performed by analysts to provide forecast of the impact of predefined risks, whenever

the relevant event and system data are available. Examples of quantitative approaches include estimation of cascading failure propagation in electric power system (Baldick at al., 2008) and those devoted to compute the losses due to an earthquake (Silva et al. 2014). The qualitative approach for risk assessment is especially useful to identify possible new risks for an area, as the so-called *black swan* events. However current practices of qualitative risk assessment are heavily based on human judgment and experience, and this may weaken completeness and reliability of the results. Therefore, as a new research, we are facing the problem of how to automatize some human activities of qualitative risk assessment by exploiting Artificial Intelligence techniques.

In this context we propose an automatic approach to qualitative risk assessment in urban areas that aims at conceiving new risks for points of interest (POIs) in metropolitan areas and at prioritizing them. Examples of points of interests are hospitals, police stations, museums and restaurants. The approach is enabled by a software system that, in particular, generates conceptual models of risks, named risk mini-models (Coletti et al. 2017), and locates them on a map. The system consists of three main components: TERMINUS (Coletti et al. 2018), a domain ontology formalizing knowledge concerning environment, city services and infrastructures and related risks; WS-CREAM, a web service implementing the computational support for automatic risk identification and ranking, by querying the ontology and using context data; and CIPCast, a GIS-based tool for critical infrastructures protection, enhanced with forecasting and decision support functionalities.

The TERMINUS ontology was built by means of ontology design patterns. An ontology design pattern is a reusable conceptual structure with the aim of supporting the ontology engineering process (Gangemi and Presutti, 2009). WS-CREAM implements semantic queries automatically built from pre-specified ontology patterns[1].

Then we present the guidelines to perform qualitative risk assessment by means of the proposed software. The activities concern both the system set up and the actual qualitative risk assessment process.

As a case study we present the experience we had on qualitative risk assessment in the city of Rome. In particular, we focused on two areas with different characteristics. The former, the area close to Ponte Milvio, is located in the city center and close to the Tevere river. The latter, close to Colli Albani, is located nearby a lake and it is threatened by earthquakes. We discuss a preliminary experts' validation of the generated risk mini-models concerning the points of interest of these two areas.

The rest of the paper is organized as follows. The second section presents relevant work in the area. The third section describes the proposed software system for qualitative risk assessment. The fourth section presents the guidelines to perform qualitative risk assessment using the system. The fifth section describes the preliminary results of a case study of qualitative risk assessment in the city of Rome. Finally the last section presents conclusions.

RELATED WORK

This paper deals with risk assessment for metropolitan areas. As stated in Introduction the most common approaches for this purpose are quantitative and qualitative risk assessment. Among the existing works on quantitative risk assessment we cite: the seismic vulnerability and risk assessment performed by (Vicente et al., 2011) for the city of Coimbra in Portugal; the earthquake risk assessment for Istanbul metropolitan area treated by (Erdik et al., 2003); and the quantitative risk assessment performed by (World Health Organization, 2014) that, among the different causes of death, includes also costal flood mortality. Among the existing works concerning qualitative risk assessment we cite (Rinaldi et al. 2001) that discusses the risks due to interdependencies of critical infrastructures, With respect to these works our proposal addresses both approaches as CIPCast is mainly devoted to quantitative risk assessment whereas WS-CREAM, together with CIPCast, addresses qualitative risk assessment.

There are different initiatives in the literature devoted to building ontologies related to risk assessment. One of the first initiatives is the vulnerability upper model and the VUM ontology presented by (Coletti et al., 2016). The VUM ontology includes concepts as risk, threat, system, stakeholder, severity, and vulnerability Then this ontology was extended to build the first version of the TERMINUS ontology presented in (Coletti et al., 2018). After these, other initiatives include the common ontology of value and risk presented by (Sales T.P. et al. 2018) and the ontology of emergency managing and planning about hazard crisis presented by (Gaur, M. et al. 2018).

At the best of our knowledge, our is the first approach devoted to automatizing human activities of qualitative assessment and linking risk descriptions to system components on a map to the purpose of analysis.

[1] Similarly to an ontology design pattern, in the following, an ontology pattern is a reusable semantic model, based on the ontology that supports the definition of queries.

SOFTWARE SYSTEM FOR QUALITATIVE RISK ASSESSMENT

The automatic approach for qualitative risk assessment is realized within a wider system whose architecture is illustrated in Figure 1. Specifically, such a system realizes interoperation of two pre-existing applications, such as an ontology-based CREAtivity Machine Web Service (WS-CREAM) and CIPCast, a GIS-based Decision Support System (DSS) for critical infrastructures protection with a web interface. A middle layer, such as the Semantic data Integrator, was realized to manage communication between the two independent back-end components. In summary, for a user selection of an urban area and of a natural hazard from the WebGIS interface (i.e. CIPCast front-end), TERMINUS ontology, representing city knowledge, together with context data managed by CIPCast geodatabase, are used by WS-CREAM to generate ranked lists of risk descriptions for the services belonging to that areas. These risks, after off-line validation, are shown on the map as result.

A more detailed description of the system components follows.

The CIPCast Decision Support System

CIPCast is a novel Decision Support System (DSS) (Giovinazzi et al., 2017) able to produce a real-time operational risk forecast of CI in a given area due to natural hazards. The main functionalities of CIPCast are: (i) real-time monitoring of natural phenomena; (ii) prediction of natural events (if predictable); (iii) prediction of damage scenario on critical infrastructure components; (iv) prediction of impacts on critical infrastructure services and impacts on citizens and (v) definition of efficient strategies to support decision-making operator processes.

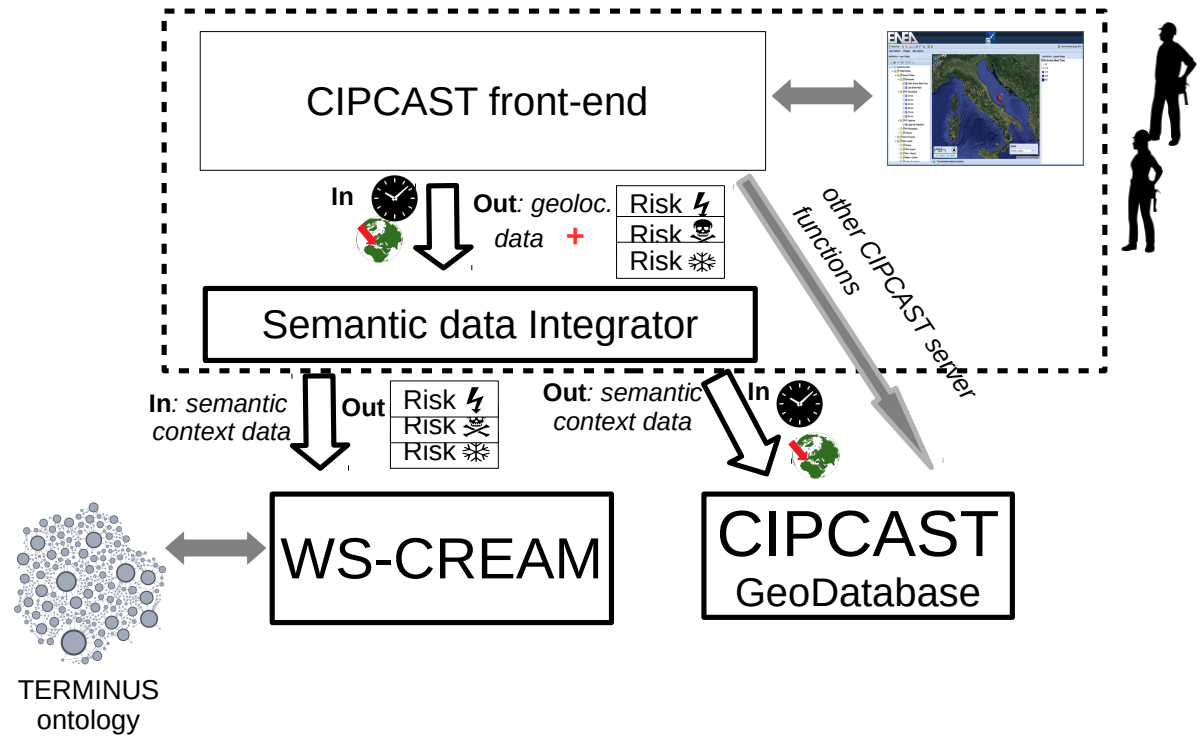


Figure 1 Illustration of the software architecture and information flow

CIPCast was conceived as a combination of free/open source software (FOSS) environments including Geographic Information System, GIS features, which play a major role in the construction of such a tool. Multisource data and GIS-integrated analysis can contribute to a better emergency planning, providing fundamental information for immediate response. The creation of this information consultation tool, enriched by the geospatial component, implies the adoption of a specific and suitable GIS architecture (commonly indicated as SDI, Spatial Data Infrastructures). In order to store and share all data and information available (base cartography, risk maps, CI features data, data from sensors, scenario produced, etc.), a PostGIS[2]-based

[2] https://postgis.net/

Geodatabase for data storage and management was implemented. The Geodatabase can be directly accessed by means of different desktop GIS software suites (e.g., QGIS). In addition, by means of the server stratum, composed by GeoServer[3], data can be accessed via web by using OGC standards[4] (WMS, WFS and WCS services).

Moreover, CIPCast provides a user-friendly geographical interface, implemented through a specific WebGIS application[5], for querying and analysing geographic data and thematic maps, execute processes and simulations, produce and evaluate scenarios, etc. Thanks to the WebGIS interface, the main results produced within CIPCast can be easily accessible to the users and exploitable for further analyses.

An Ontology for Territorial Management and Infrastructures

TERMINUS (TERritorial Management and INfrastructures ontology for institutional and industrial USage) is a domain ontology including knowledge representing environment, critical infrastructures and related hazards, risks and threats. An ontology is a formal specification of a shared conceptualization (Gruber, 1993) (Borst, 1997). It defines concepts, relationships, and axioms relevant for representing a domain of interest. TERMINUS has been built by extending some ontology design patterns. At the current stage, TERMINUS has been built by deriving concepts from the *vulnerability upper model* (VUM) design pattern (Coletti et al., 2016), from the *system aspect* design pattern presented by (Coletti et al., 2018) and from the *risk of system service* design pattern that is presented in the following. It also includes knowledge related to interdependencies between critical infrastructures (Rinaldi et al., 2001). In particular the *risk of system service* design pattern allows representing risks for city services due to catastrophic events as earthquakes, floods, and landslides. This ontology design pattern is depicted in Figure 2. It consists of five upper level concepts: `Hazard`, `Critical_event_of_system`, `Functional_vulnerability`, `System_service`, and `Stakeholder`. The descriptions of these five upper level concepts is presented in Table 1 whereas the descriptions of the relationships between them is presented in Table 2.

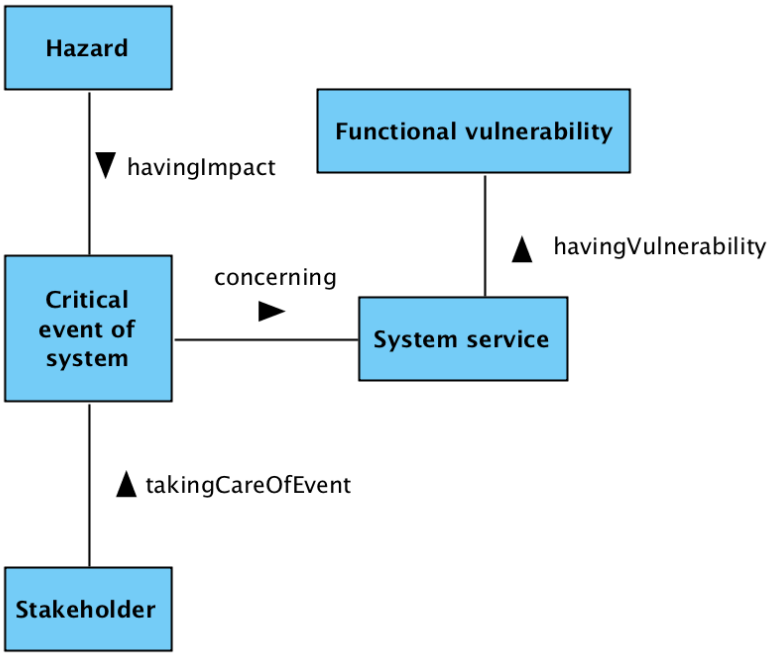


Figure 2. UML class diagram of the risk of system service ontology design pattern

[3] http://geoserver.org/

[4] Open Geospatial Consortium standards: http://www.opengeospatial.org/docs/is

[5] Developed exploiting the GeoPlatform FOSS suite: https://github.com/geosdi/geo-platform

Table 1. Description of the five upper level concepts belonging to the *risk of system service* ontology design pattern

Concept name	Description
`Hazard`	Climate-related event or trend or their impacts on geophysical systems (e.g., floods, droughts and sea level rise) with likely detrimental consequences to human systems (Mora et al. 2018).
`Critical_event_of_system`	Event representing one or more effects on systems from exposure to a hazard; effects are mediated by the strength of the hazard and the vulnerability of the exposed system (Adapted from the Impact concept description in Mora et al. 2018).
`Functional_vulnerability`	The propensity of a system function to be adversely affected. This results from the balance between sensitivity and adaptive capacity (Adapted from the Vulnerability concept description in Mora et al. 2018).
`System_service`	Service provided by system.
`Stakeholder`	A person or organization that is interested in a system or its subsystems.

Table 2. Description of the relationships between the concepts belonging to the *risk of system service* ontology design pattern

Object property name	Description
`havingImpact`	Conceptual relationship between a `Hazard` and a `Critical_event_of_system`.
`concerning`	Conceptual relationship between a `Critical_event_of_system` and one of its provided services (i.e. `System_service`).
`havingVulnerability`	Conceptual relationship between `System_service` and one of its function vulnerabilities (i.e. `Functional_vulnerability`)
`takingCareOfEvent`	Conceptual relationship between `Stakeholder` of a system and `Critical_event_of_system`.

Figure 3 shows an excerpt from TERMINUS ontology showing a fragment of the taxonomy related to the `System_service` concept.

WS-CREAM

The CREAtivity Machine (CREAM) Web Service is a software application that, more generally, is capable to automatically generate semantic descriptions of future situations that may be significant in some given application domain to the purpose of analysis. These situations refer, for example, to possible emergencies in a city or to risks for infrastructures or enterprises. The aim is to support a user, such as a risk analyst or a city planner, to imagine possible futures and identify those relevant for her final objectives, including city emergency management and/or risks mitigation. Indeed, this component provides an automatic ranking of the generated situations, based on context information, a useful function to speed up the subsequent qualitative assessment activity by the user, .

From a technical perspective, WS-CREAM has been realized to be independent from the specific application (risk assessment or emergency scenarios planning), hence to be adaptable to different uses by means of some configuration information.

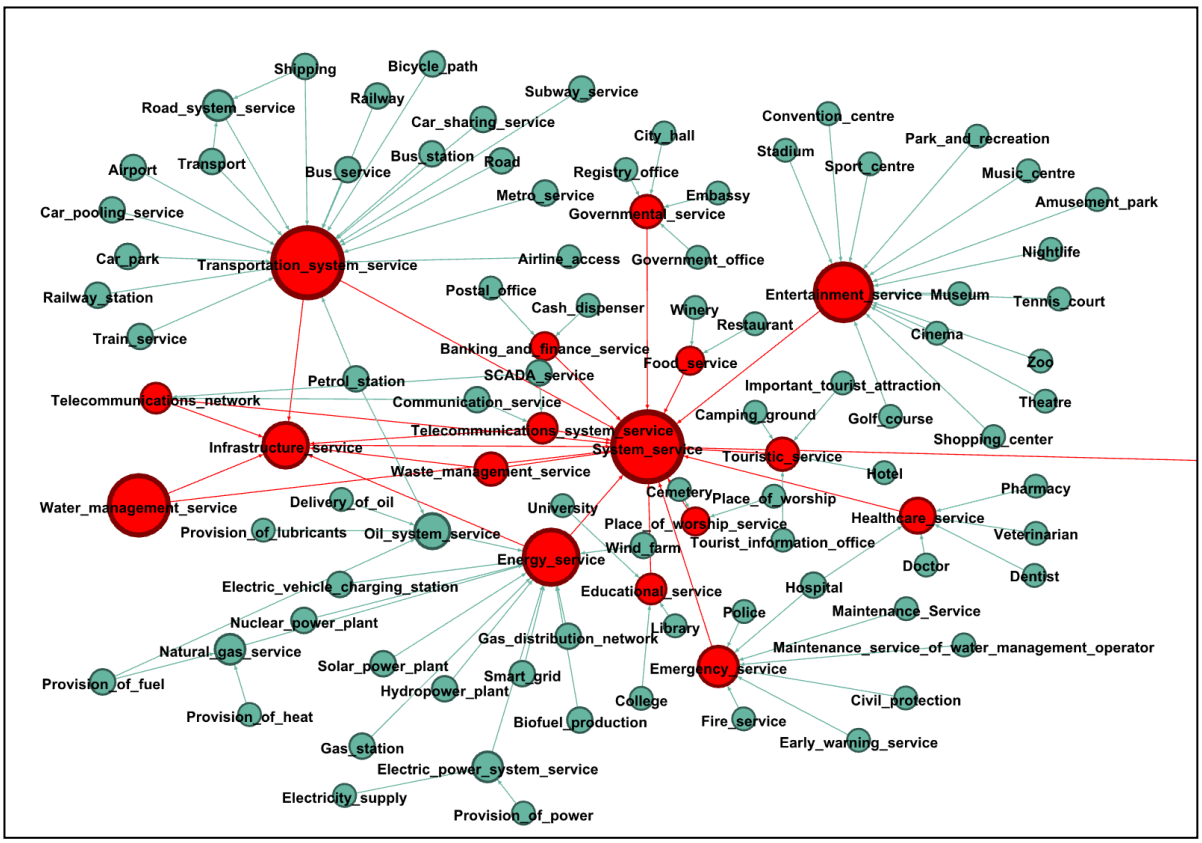


Figure 3. Excerpt from TERMINUS ontology showing a fragment of the taxonomy related to the `System_service` concept

In this work, WS-CREAM uses the following input configuration specifying:

- the **application domain**, here represented by the TERMINUS ontology;
- the **semantic structure** (by means of a formal ontology pattern) of the information on the situation to be represented. Here such a structure is described in OWL and it is based on the ontology design pattern described previously. The output risks will be described as records of the following table.

  [*System service*, *Hazard*, *Functional vulnerability*, *Critical event of system*, *Stakeholder*] (1)

- a **ranking formula** to be applied to order by relevance level the generated risks for each city service. Such a formula is defined by the metrics: context-specific properties of the service, such as its relevance as point of interest in the given city, its physical exposure to risks caused by the given hazard; and context-independent properties of the service, such as the service criticality compared to other services of a city (e.g., hospital versus monument). The formula also specifies the aggregation operations of those variables.

For the application presented in this paper, as a trial, the ranking formula is the *average* of the relevance levels attributed to some components of the ontology design pattern, that is: the *relevance* of the specific service in the city, such as its *value* or *criticality* in the city, associated with the *System service* component in (1); the *risk level* from a natural hazard, referred to the geographical location of the service, associated with the *Hazard* component of (1); the *criticality level* of the described impact of the natural event on the service, compared to other types of impact, associated with the *Critical event of system* component of (1); the *relevance level* of the functional vulnerability, compared to other known vulnerabilities, associated with *Functional vulnerability*.

Given such a configuration, WS-CREAM provides a function that takes as input a list of semantically annotated services present in a user selected urban area, their contextual properties; and possibly the type of hazard with its associated properties. A SPARQL query (Coletti et al., 2017) is automatically built from a pre-defined ontology pattern addressed in the configuration file, which is run on the TERMINUS ontology to retrieve a list of semantic descriptions of possible service risks as records of (1). These records are built with concepts of TERMINUS, where the *System service* component specifies the type of service provided as input, and, possibly, the *Hazard* component specifies the type of chosen hazard. For each city service, WS-CREAM computes a relevance level of each generated risk (in a ordinal scale from 1 to 5), using the ranking formula. The output will

be a set of associations of the city services with their ranked lists of risks.

GUIDELINES FOR QUALITATIVE RISK ASSESSMENT

In our proposal qualitative risk assessment requires six activities. The first three activities are related to the system set up, whereas the last three concern the actual qualitative risk assessment process.

1. **Points Of Interest (POI) identification.** This set up activity consists in identifying points of interest located in the area considered for the analysis, like restaurants, hospitals, cinemas and governmental offices.
2. **Semantic annotation of the POIs**. This set up activity consists in providing a formal meaning to the points of interest identified in step 1. So each point of interest is associated with a formal expression. For instance, POI:`Stadio_Olimpico IS_INSTANCE_OF TERMINUS:Stadium` specifies that *Stadio Olimpico* of Rome is annotated by the `TERMINUS:Stadium` ontology concept.
3. **Definition of the ranking mechanism**. This set up activity consists in deciding the ranking formula and collection of the required data to prioritize the generated risks.
4. **Risk mini-model generation for a selected area**. This activity consists in using the system to generate ranked risk descriptions, named risk mini-models (RMM), for the POIs of the selected area.
5. **Risk mini-model validation**. This activity involves experts to assess RMM usefulness and relevance.
6. **Geolocalization of risk mini-models**. This activity consists in using the system to visualize the valid risk mini-models on a map.

CASE STUDY: QUALITITATIVE RISK ASSESSMENT IN ROME (ITALY)

This case study is related to qualitative risk assessment concerning two areas of Lazio (Italy): the area near Ponte Milvio, in the center of Rome and close to the Tevere river, and Colli Albani, an area on the hills in the south-east of Rome. For these areas we identified the points-of-interests.

Ponte Milvio

Considering the morphology of this area and its proximity to Tevere river, our study focused on the alluvial event that, historically, has frequently occurred in this area. The points-of-interests located in this area are all located inside buildings and mainly include medical offices, dental offices, restaurants and are homogeneously located throughout the territory. Some of such points-of-interests are particularly relevant due to their high occupancy rate. These include the Olympic stadium, the Auditorium Parco della Musica, the Palazzetto dello Sport and the IUSM University of Rome. Regarding the presence of points-of-interests not included into buildings, these include petrol stations and tennis courts.

Colli Albani

This area, including a portion of territory between the lakes of Albano and Nemi, has suffered damages following seismic events in history. The points-of-interests are all located inside buildings and, mainly, include restaurants, medical offices, veterinary offices, dental clinic, museums, hotels and libraries.

In the following we present a risk mini-model for the Ponte Milvio area and another one for the area of Colli Albani. These were selected by experts as representatives of the most relevant risk mini-models. Each risk mini-model is followed by a description written by the expert, in the form of an imagined story or report of a known situation. The purpose is to provide context-based interpretation of the risk mini-model and to support risk plausibility. This method follows the approach to stimulate creativity presented by (De Nicola et al., 2019).

Ponte Milvio risk mini model

```
Functional_vulnerability: People_inside

System_service: Nightlife

Critical_event_of_system: Health_and_physical_consequences

Stakeholder: Unspecified_person

Hazard: Flood
```

Description
A flood occurred in the center of Rome; it hits a very popular nightclub of the area while this was registering its maximum capacity of customers. The water caused physical damages and also health consequences to people inside the nightclub. Indeed, the panic of the mass generated fights to exit the structure resulting in several injured persons.

Colli Albani risk mini-model
`Functional_vulnerability: Presence_of_electric_elements_potentially_dangerous`
`System_service: Doctor`
`Critical_event_of_system: Economic_damage`
`Stakeholder: Manager`
`Hazard: Earthquake`
Description
It is 9:00 am on a weekday. The waiting room of a medical office is, as usual, full of: patients waiting for their turn; secretaries; doctors and staff involved in their work. At 9:15 a strong earthquake causes breakage of machinery and electrical tools that begin to fall dangerously over the patients; moreover, the general panic in the waiting room grows as the large neon lights come off the supports, creating some injuries. A few minutes later the medical office is evacuated, but the general chaos produces considerable damage to electrical equipment and specialist instruments, computers and printers, the general electrical panel, lights, etc. These damages have an economic impact on the medical service .

In the following we present the analysis of the results after the experts' validation of the risk mini-models generated by WS-CREAM. Table 3 shows the number of relevant risk mini-models with respect to the overall set. It shows that, for the two considered areas, the percentages of relevant risk mini-models are 37.77% and 53.88%. As a future work, discarded risk mini-models will be used to learn rules to improve precision of the generative function of WS-CREAM.

Table 3. Number of relevant generated risk mini-models according to the expert's judgment. This analysis considers the type of system service.

Area	Relevant risk mini-models	Overall risk mini-models	Percentage of relevant risk mini-models
Ponte Milvio	431	1141	37.77%
Colli Albani	534	991	53.88 %

Table 4 shows the degree of relevance of generated risk mini-models according to the expert's judgment. It should be noted that the numbers of risk mini-models are higher with respect to those presented in Table 3 as here these numbers include POI instances. This means that there could be more than one medical office in the selected area.

Table 4. Degree of relevance of generated risk mini-models (by POI) according to the expert's judgment. This analysis considers the different POIs (there could be more POIs for one type of system service).

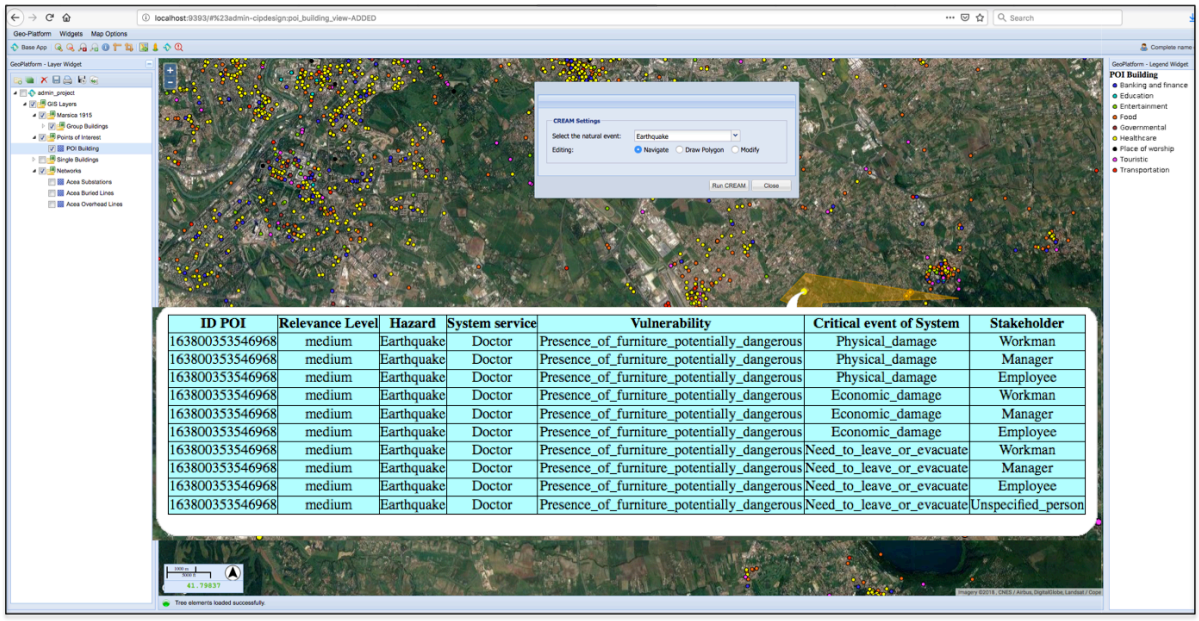
Area	Number of relevant risk mini-models	High relevance	Medium relevance	Low relevance
Ponte Milvio	827	124 (14.99%)	431 (52.12%)	272 (32.89%)
Colli Albani	809	343 (42.39%)	162 (20.02%)	304 (37.58%)

Table 5 shows the degree of relevance of generated risk mini-models according to WS-CREAM ranking.

Table 5. Degree of relevance of generated risk mini-models (by POI) according to WS-CREAM ranking. This analysis considers the different POIs (there could be more POIs for one type of system service).

Area	Number of relevant risk mini-models	High relevance	Medium relevance	Low relevance
Ponte Milvio	2122	1180 (55.61%)	942 (44.39%)	0 (0%)
Colli Albani	1472	0 (0%)	1320 (89.67%)	152 (10.33%)

Then we compared the relevance level assigned by the experts to risk mini-models with that assigned automatically by WS-CREAM. We found that the expert and the software judgments were the same for 210 out of 809 risk mini-models (25.96%) in case of the area of Colli Albani and for 373 out of 827 risk mini-models (45.10%) in case of the area of Ponte Milvio. Again we expect to improve these numbers in the near future, for instance, by gathering more accurate context-specific and context-independent data and experiencing different ranking formulas. Finally Figure 4 shows a screenshot of CIPCast including the risk mini-models generated by WS-CREAM for the point of interest doctor in case of flooding.



ID POI	Relevance Level	Hazard	System service	Vulnerability	Critical event of System	Stakeholder
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Physical_damage	Workman
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Physical_damage	Manager
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Physical_damage	Employee
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Economic_damage	Workman
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Economic_damage	Manager
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Economic_damage	Employee
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Need_to_leave_or_evacuate	Workman
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Need_to_leave_or_evacuate	Manager
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Need_to_leave_or_evacuate	Employee
163800353546968	medium	Earthquake	Doctor	Presence_of_furniture_potentially_dangerous	Need_to_leave_or_evacuate	Unspecified_person

Figure 4. Risk mini-models associated to points of interest located in the area of Colli Albani (Rome) in case of flooding.

CONCLUSION

Qualitative risks assessment for metropolitan areas is a complex activity due to uncertainties on hazards and to the variety of systems. WS-CREAM is a novel software system aiming to provide descriptions of relevant risk situations with semantic reasoning applied to a domain ontology. As risk assessment requires data on the geographical areas and on the societal and infrastructures' characteristics of the specific system under analysis, WS-CREAM has been integrated with CIPCast, which is a GIS-based tool for CI protection, enhanced with forecasting and decision support functionalities. In this work, we presented how these two systems interoperate to perform qualitative risk assessment for metropolitan areas. We presented also preliminary validation results of the approach. These results provided us future work directions to improving selectivity of the risk mini-models generation function and precision of the automatic assessment.

ACKNOWLEDGMENTS

This work was partially supported by the Italian project Accordo di Programma Ministero dello Sviluppo Economico — ENEA, Ricerca di Sistema Elettrico.

REFERENCES

Baldick, R., et al. (2008). Initial review of methods for cascading failure analysis in electric power transmission systems IEEE PES CAMS task force on understanding, prediction, mitigation and restoration of cascading failures. *Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century*, IEEE.

Borst, W. N. (1997) Construction of engineering ontologies for knowledge sharing and reuse. Universiteit Twente.

Gruber T.R. (1993) A translation approach to portable ontology specifications. *Knowledge acquisition*, 5(2), 199-220.

Coletti A., De Nicola A., Villani M.L. (2016) Building climate change into risk assessments, *Natural Hazards*, 84(2).

Coletti A., De Nicola A., Villani M.L. (2017) Enhancing Creativity in Risk Assessment of Complex Sociotechnical Systems. In: Gervasi O. et al. (eds) *Computational Science and Its Applications* – ICCSA 2017. ICCSA 2017. Lecture Notes in Computer Science, vol 10405. Springer, Cham.

Coletti A., De Nicola A., Vicoli G., and Villani M.L. (2018) Semantic Modelling of Cascading Risks in Interoperable Sociotechnical Systems, *Proceedings of I-ESA 2018*.

De Nicola A., Melchiori M., Villani M.L. (2019) Creative design of emergency management scenarios driven by semantics: An application to smart cities. *Information Systems*, Vol. 81, 21-48, https://doi.org/10.1016/j.is.2018.10.005.

Erdik, M., et al. (2003). Earthquake risk assessment for Istanbul metropolitan area. *Earthquake Engineering and Engineering Vibration*, 2(1), 1-23.

Gangemi A. and Presutti V. (2009). Ontology design patterns, In: *Handbook on Ontologies*, 2nd edn. *International Handbooks on Information Systems*. Springer, Heidelberg.

Gaur, M., Shekarpour, S., Gyrard, A., & Sheth, A. (2018). empathi: An ontology for Emergency Managing and Planning about Hazard Crisis. arXiv preprint arXiv:1810.12510.

Giovinazzi S., Pollino M., Kongar I., Rossetto T., Caiaffa E., Di Pietro A., La Porta L., Rosato V., Tofani A. (2017) Towards a decision support tool for assessing, managing and mitigating seismic risk of electric power networks. In: Gervasi O. et al. (eds) *Computational Science and Its Applications* – ICCSA 2017. ICCSA 2017. Lecture Notes in Computer Science, vol 10405. Springer, Cham.

Mora, C., et al. (2018). Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions. *Nature Climate Change*, 1.

Rinaldi, S. M., Peerenboom, J. P., and Kelly, T. K. (2001) Identifying, understanding, and analyzing critical infrastructure interdependencies. *IEEE Control Systems* 21(6), 11-25.

Sales, T. P., Baião, F., Guizzardi, G., Almeida, J. P. A., Guarino, N., & Mylopoulos, J. (2018). The common ontology of value and risk. In International Conference on Conceptual Modeling (pp. 121-135). Springer, Cham.

Silva, V., Crowley, H., Pagani, M., Monelli, D., & Pinho, R. (2014). Development of the OpenQuake engine, the Global Earthquake Model's open-source software for seismic risk assessment. *Natural Hazards*, 72(3), 1409-1427.

Vicente, R., Parodi, S., Lagomarsino, S., Varum, H., & Silva, J. M. (2011). Seismic vulnerability and risk assessment: case study of the historic city centre of Coimbra, Portugal. Bulletin of Earthquake Engineering, 9(4), 1067-1096.

World Health Organization. (2014). Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. World Health Organization.

SEMIoTICS: Semantic Model-Driven Development for IoT Interoperability of Emergency Services

João Moreira
University of Twente, Netherlands
j.luizrebelomoreira@utwente.nl

Luís Ferreira Pires
University of Twente, Netherlands
l.ferreirapires@utwente.nl

Marten van Sinderen
University of Twente, Netherlands
m.j.vansinderen@utwente.nl

ABSTRACT

Modern early warning systems (EWSs) use Internet-of-Things (IoT) technologies to realize real-time data acquisition, risk detection and message brokering between data sources and warnings' destinations. Interoperability is crucial for effective EWSs, enabling the integration of components and the interworking with other EWSs. IoT technologies potentially improve the EWS efficiency and effectiveness, but this potential can only be exploited if interoperability challenges are properly addressed. The three main challenges for interoperability are: (1) achieving semantic integration of a variety of data sources and different representations; (2) supporting time- and safety-critical applications with performance and scalability; and (3) providing data analysis for effective responses with personalized information requirements. In this paper, we describe the "SEmantic Model-driven development for IoT Interoperability of emergenCy serviceS" (SEMIoTICS) framework, which supports the development of semantic interoperable IoT EWSs. The framework has been validated with a pilot performed with accident use cases at the port of Valencia. The validation results show that it fulfils the requirements that we derived from the challenges above.

Keywords

Early warning system, Internet-of-things, semantic interoperability, emergency service.

INTRODUCTION

An Early Warning System (EWS) is a distributed information system that is able to monitor the physical world and issue warnings if it detects abnormal situations (Waidyanatha 2010). A multi-hazard EWS (MHEWS) is a special type of EWS that integrates two or more EWSs in order to be able to detect and react upon different types of situations (UNISDR 2015). EWSs can benefit from Internet-of-Things (IoT) technologies (Poslad, Middleton et al. 2015) to realize (near) real-time data acquisition, risk detection and message brokering between data sources and information receivers, comprising both humans (e.g., emergency managers) and machines (e.g., sirens).

Interoperability is crucial for effective EWSs to enable the integration of EWS components, e.g., sensors, devices and platforms, and the interworking among EWSs (Wächter and Usländer 2014). Although IoT technologies can potentially improve the EWS efficiency and effectiveness, this potential can only be exploited if interoperability challenges are addressed (Middleton, Zlatev et al. 2013). In this paper, we focus on how to improve the semantic interoperability of IoT EWSs, i.e., how to enhance the ability of two or more EWSs (or EWS components) to share data elements in a precise format (syntax) and well-established meaning (semantics).

In a literature review on interoperable EWSs (Moreira, Pires et al. 2018), we identified three major challenges: (1) semantic integration of a variety of data sources that adhere to different standards, ontologies and data models; (2) near real-time processing in time- and safety-critical applications; and (3) data analysis for effective situation awareness and decision support.

This paper describes the "SEmantic Model-driven development for IoT Interoperability of emergenCy serviceS" (SEMIoTICS) framework. SEMIoTICS enables the model-driven development of interoperable IoT EWSs in different domains, so that an IoT EWS can act as a cloud-based semantic broker for situation-aware decision support. SEMIoTICS is leveraged by ontology-driven conceptual modelling for situation-aware applications (Moreira, Ferreira Pires et al. 2015), covering both EWS design-time and runtime.

SEMIoTICS was validated with a case study performed in the H2020 INTER-IoT project (Ganzha, Paprzycki et al. 2016). The case study involves a semantic interoperable IoT EWS developed to detect truck accident risks at the Valencia port area. The case considers a variety of data sources and processing requirements for safety-critical applications, and applies existing domain-specific ontologies and standards, along with their serialization formats. Accident risks are assessed by monitoring the truck drivers' vital signs with electrocardiogram (ECG) wearables, and the trucks' position with speed and accelerometer data, using mobile phones as gateway. The detection targets health issues of drivers and collisions of trucks with dangerous goods. The IoT EWS is able to provide personalized emergency notifications to multiple target groups with distinct information requirements.

BACKGROUND

The term "IoT EWS" (Balis, Kasztelnik et al. 2011, Du and Zhu 2012, Poslad, Middleton et al. 2015) denotes EWSs supported by IoT technologies. Interoperability is crucial for the effectiveness of IoT EWSs and is impacted by data variety. The level of interoperability depends on the standardization of interfaces, data exchange formats and protocols (Wächter and Usländer 2014). A MHEWS usually needs to use and integrate standards from different domains to support seamless integration of distinct IoT EWSs (Keeney, Buan et al. 2012).

Early Warning System Reference Architectures

A conceptual architecture of an interoperable *Standard-Based EWS* was introduced in (Wächter and Usländer 2014), in which three consecutive steps have been identified: *Upstream Data Acquisition, Decision Support* and *Downstream Information Dissemination*. The *Upstream Data Acquisition* component is responsible for pre-processing and storing streaming data acquired from sensor systems in an internal *Context Database*. *Models* are used to represent an emergency situation identification mechanism, which can be either specification-based or learning-based. The *Decision Support* module applies the intrinsic rules of the models over the context data, supporting decision making by allowing the EWS administrator to configure actions according to the situation identified, usually with support of a workflow management system. Notifications are sent according to the pre-configured actions to different target groups through the *Downstream Information Dissemination* component, which is responsible for message brokering. The target groups can be either humans, who receive alerts through mobile applications or low-frequency radio, or actuators for automatic emergency response.

OASIS EDXL is a common standard for downstream data representation for interoperable EWSs (Chronaki, Kontoyiannis et al. 2011, Dogac, Kabak et al. , Lendholt, Esbrí et al. 2012, Poulymenopoulou, Malamateniou et al. 2012, Wächter and Usländer 2014, Barros, Kislansky et al. 2015). The *Standard-Based EWS* architecture allows the integration of EWSs through event-based message-oriented middleware (MOM), which can play the role of either a context broker or a service broker. The main limitation of this approach is that it neglects semantic interoperability.

Most of the semantic EWS approaches (Balis, Kasztelnik et al. 2011, Du and Zhu 2012, Poslad, Middleton et al. 2015, Roy, Sarkar et al. 2015, Battistini, Rosi et al. 2017) extend the *Standard-Based* architecture by using semantic technologies to represent data, both upstream and downstream, taking advantage of inference capabilities. Usually, the concept of a common information space is exploited, linking semantic technologies to SOA (Balis, Kasztelnik et al. 2011). Performance tends to be a drawback, which makes scalable time-sensitive data exchange and processing from heterogeneous data sources quite challenging.

The *Semantic IoT EWS* approach (Poslad, Middleton et al. 2015) improves semantic interoperability with a scalable solution for data exchange and processing, by providing a balanced way to use lightweight and heavyweight ontologies. Lightweight ontologies are used in *Upstream Data Acquisition* and *Downstream Information Dissemination* to reduce the message payload during data exchange and processing. Heavyweight (formal logic based) ontologies are used in *Decision Support* to add additional semantics to the data, enriching the fusion of new and historical data by enabling the discovery (inference) of new knowledge. This new information is serialized as lightweight (association based) semantics to be included in the warning messages that are brokered through the downstream information dissemination component. This balance of heavyweight and lightweight ontologies enables scalable time-sensitive data handling from heterogeneous sources with effective responses.

The *Semantic IoT EWS* approach introduced a heavyweight ontology by reusing terms from the W3C Semantic Sensor Network (SSN) and incorporates terms from the OGC Observations and Measurements (O&M) standard. W3C SSN is the most popular lightweight ontology in the IoT domain, founded on the OGC SWE standards. Upstream sensor data are annotated only with SSN predicates. Annotation is applied at the broker (gateway) level, since sensors only need to interoperate with a control centre via a sensor's access node.

Internet-of-Things Platforms

An IoT platform enables ICT solution engineers to bridge the gap between device sensors and connected applications through suites of components. All big players in cloud services provide a general-purpose IoT platform, such as Microsoft (Azure IoT), Google (IoT), IBM (Watson IoT) and Amazon (AWS IoT). Some IoT platforms are domain-oriented, such as Google Fit and Apple Health for healthcare. The enabling technologies underlying an IoT platform include: sensor networks and cloud computing, RESTful microservices (usually with JSON), relational and NoSQL databases, distributed Complex Event Processing (CEP) engines and message/event-oriented middleware.

MyDriving[1] is the open source[2] use case of the Azure IoT platform, which provides a starting point for scalable, high-performance and cross-platform IoT implementation. *MyDriving* targets users who want to increase their awareness of their driving habits and improve safety and long-term vehicle performance. Real-time telemetry data are collected from the vehicle, such as location, speed, instantaneous acceleration, distance, fuel consumption, temperature and RPMs. These data are processed both locally in the field and in the cloud, providing meaningful information that can be accessed through various types of interfaces. A mobile phone plays two roles in this application: (1) it collects and transmits data as an IoT "field gateway"; and (2) it provides data visualization with maps, both real-time and past trips. The solution can be leveraged by using an On-Board Diagnostic (OBD 2) sensor, which is able to send more accurate vehicle telemetry data to the mobile phone via Bluetooth. Data are aggregated at the field gateway and published into the Azure message-oriented broker (IoT Hub) in JSON format. A RESTful microservice subscribes to the data, storing in parallel JSON documents in a blob database ("warm path"), and in a relational database ("cold path"). The solution makes use of *Streaming Analytics*, a kind of distributed CEP engine that subscribes to receive all data published in the IoT Hub, being able to integrate historical data in the warm path. It also allows to apply machine learning in the cold path to identify driving habits.

Some of the research-oriented IoT platforms include semantic technologies, such as FIWARE with the Sense2Web for RDF, the universAAL internal semantic models, and the OpenIoT with an ontology extended from SSN. In this context, we mention the INTER-IoT project, which aimed at designing, implementing and experimenting with interoperability among heterogeneous IoT platforms (Ganzha, Paprzycki et al. 2016). The project was driven by use cases from e-Health and transportation/logistics at the port of Valencia, addressing semantic integration among IoT artefacts. INTER-IoT developed the Inter-Platform Semantic Mediator (IPSM) tool to support the semantic integration at runtime when multiple-ontology translations are required (Ganzha, Paprzycki et al. 2017).

Challenges and Requirements

In an earlier work (Moreira, Pires et al. 2018), we concluded that the cross-disciplinary nature of the emergency field made it necessary to match conceptualizations and combine multiple domain ontologies, in order to provide a higher level of interoperability for EWSs that acquire data fusion from multiple sources. *Semantic Gateways* address this issue by enabling the execution of semantic translations that can tackle specific semantic integration problems, such as semantic overload, ambiguity and information distortion (Kim, Kang et al. 2012).

To the best of our knowledge, approaches with *Semantic Gateway* that support the whole lifecycle of semantic translations (specification, implementation, and runtime configuration) have not been exploited yet in any EWS initiative. Although some researchers point out that such approaches are needed in order to more effectively apply the use of semantic models within EWSs (Poslad, Middleton et al. 2015), results are still lacking in the literature. A particular need that emerged for EWSs is the ability to interoperate with health monitoring systems that support medical emergency services (Clinton, Zollo et al. 2016) using *e-Health* standards.

The *Semantic IoT EWS* includes an approach that can handle multiple ontologies to support compound EWS semantics and ontology commitments. However, this approach lacks support to the development of alignments between domain ontologies that can be configured at runtime, i.e., it does not provide a mechanism for

[1] https://azure.microsoft.com/en-us/campaigns/mydriving/

[2] https://github.com/Azure-Samples/MyDriving

describing and executing semantic translations. Furthermore, efficiently publishing large volumes of semantically rich sensor data is a major architectural challenge due to inefficient data exchange caused by the overhead imposed by the encoding schemas of the current semantic models, e.g., OWL or RDF serialized as XML, requiring research especially for EWSs (Middleton, Zlatev et al. 2013).

Our ambition is to enable EWS semantic interoperability for disaster risk reduction by considering not only IoT ontologies, but also addressing cross-domain relationships through the alignment of multiple domain ontologies. Therefore, our research goal is to improve the semantic interoperability of emergency services for IoT EWSs. We identified the following challenges to achieve this goal, along with the corresponding requirements to the supporting framework:

(C1) Semantic integration of a variety of data sources

(Req1) Enable the development of an EWS core context model as a well-founded ontology, taking into account existing data representations and possible restrictions from the EWS requirements.

(Req2) Enable the development of an EWS data acquisition component to be able to process data from different sensor types described with different semantic models, i.e., provide syntactic and semantic interoperability.

(Req3) Enable a data fusion mechanism for EWS, allowing it to combine incoming real-time data with historical data, both for situation identification and for upstream information dissemination.

(C2) Processing in time- and safety-critical applications

(Req4) Enable the EWS to provide adequate performance, in terms of total processing time, which depends on the specific safety-critical restrictions regarding minimal response time. If the EWS requirements explicitly restrict the minimum time thresholds, the EWS should be able to process within this threshold.

(Req5) Enable the EWS to be scalable according to the data input volume and velocity, i.e., be able to allocate resources according to the number of data sources, their input frequency and message size.

(Req6) Enable a dynamic and adaptive mechanism to modify the EWS at runtime, minimizing the effect on the running instances.

(C3) Data analysis for effective responses

(Req7) Offer modelling capabilities for the representation of temporal relations among different types of events and situations. In particular, it must enable the EWS to use interval relationships, such as Allen's operators, to relate events for situation identification.

(Req8) Enable the representation of complex rules over context data, such as multivariate functions (risk, odds, rate and prevalence) and temporal existential rules (sliding time windows).

(Req9) Enable the EWS to issue warnings, as semantic enriched messages, to multiple targets through multiple channels (e.g., broker, e-mail, SMS). In particular, enable the modification of the information requirements of the targets at runtime through an UI.

SEMIoTICS FRAMEWORK

Our SEMIoTICS framework aims at improving the semantic interoperability of EWSs and their components, and addresses the interoperability challenges mentioned above. The first version of SEMIoTICS was reported in (Moreira, Ferreira Pires et al. 2015), which evolved to the architecture presented in (Moreira, Pires et al. 2018). SEMIoTICS consists of an architecture, which is illustrated in Figure 1, IoT platform technologies and MDE methodology guidelines. The MDE methodology guides the choice and application of the technologies according to the reference architecture.

Reference Architecture

The architecture consists of components that address the activities of the EWS workflow for real-time data processing. *Subscriber REST/RDF* and *Input Handler* are responsible for the *sense* activity, thus, implementing the *Upstream Data Acquisition* component of the *Standard-Based* architecture. Data are acquired by the EWS by subscribing to a context broker, which should provide data in RDF, either directly from the sensors or from a semantic gateways, which can be deployed in the field (e.g., in a mobile phone) or in the cloud (e.g., in a semantic web application). *Input Handler* is responsible for checking whether the EWS is capable of

understanding the data, i.e., if the data messages comply with the EWS ontology profile represented by *Context Model*. If the data cannot be understood, then *Input Handler* should check the pre-defined ontology alignments to execute semantic translations to transform the data.

If the EWS is capable of understanding the data, the (translated) messages are forwarded to *Context Data Manager*, which is responsible for storing the data in context database(s) and to forward them to *Situation Identification Manager*, which uses *Situation Type Rules* that can be executed by CEP engines. This situation identification mechanism addresses the *detect* activity of the EWS workflow. *Situation Model* uses data elements of *Context Model* for defining situation types at an abstract level.

Once the CEP engine detects a situation, it sends the related data to *Situation Reaction Manager*. *Situation Model* is linked to emergency response processes through *Action Model*, which specifies the procedures to react to the situation, usually derived from emergency plans. *Action Model* specifies the targets that need to receive the emergency notifications, considering the information requirements of each target and the channels to broker the messages. This approach enables personalized response activities, improving the emergency response effectiveness. Therefore, *Situation Reaction Manager* performs the *decide* activity of the EWS workflow.

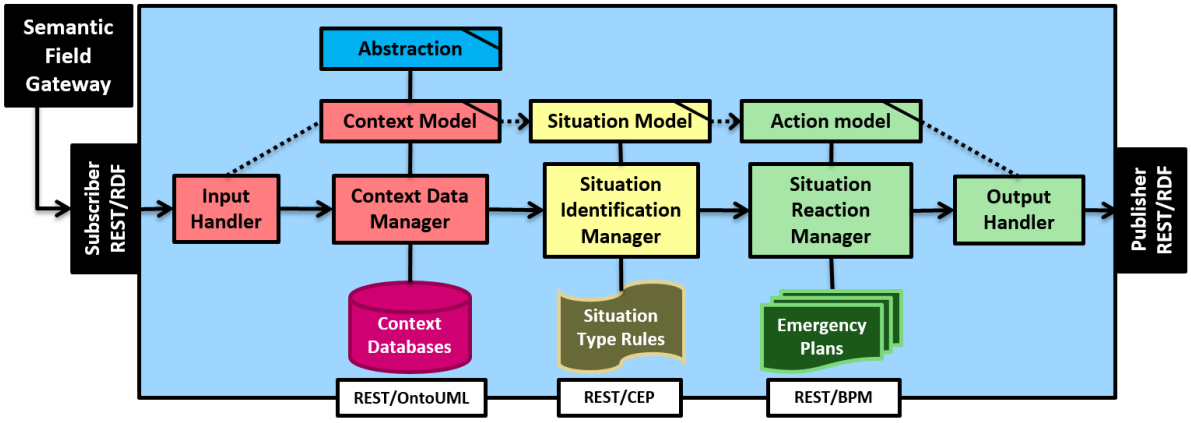


Figure 1. SEMIoTICS reference architecture

The *broker* activity is performed by *Output Handler* and *Publisher REST/RDF*, which together implement the *Downstream Information Dissemination* element of the *Standard-Based* architecture. Data are represented with standard-oriented emergency semantics, using the EDXL-CAP standard extended with the required contextual information structure (derived from *Context Model*). These messages are made available for the targets by publishing the data in a service broker, as an emergency notification publisher, and through other channels, such as e-mail and SMS.

Data stored in *Context Database(s)*, *Situation Type Rules* and *Emergency Plans* can be accessed through RESTful services. Both *Situation Type Rules* and *Emergency Plans* allow the management of the pre-defined linked situation and action models (emergency procedures). They provide data according to appropriate languages: ontological language, event processing language and business process language, respectively. Therefore, SEMIoTICS allows an EWS to share not only the data, but also all its "internal knowledge", namely: raw and processed data (for perception), situation rules (for comprehension) and reaction plans (for projection of future status).

Semantic Model-Driven Methodology

SEMioTICS follows a semantic Model-Driven Engineering (MDE) approach. The SEMIoTICS MDE methodology prescribes specification and implementation phases at design-time, considering the EWS deployment at runtime. The design-time level is organized in three interrelated parts: (1) Conceptual: presents the definition of real-world constructs in a foundational ontology, with temporal and structural aspects being addressed by extending the Unified Foundational Ontology (UFO). (2) Specification: covers the EWS design, adopting improved modelling languages as graphical modelling languages for context, situation and reaction. (3) Implementation: realizes the specification as executable pieces of software with IoT platform components.

Therefore, the conceptual part supports the modelling language constructs of the specification part, which is mapped onto the appropriate technology implementations by our model-driven engineering process, through model transformations. As usual in MDE, the implementation is (partially) generated by model transformations that integrate models and generate code for each component of the architecture according to use case requirements. Horizontal (same abstraction level) exogenous (different languages) transformations are applied at

the specification level, from the context model, represented with OntoUML, to the situation model, represented with the Situation Modeling Language (SML), and from the situation model to the action model, represented with BPMN, as described in (Moreira, Ferreira Pires et al. 2015, Moreira, Ferreira Pires et al. 2017).

In SEMIoTICS, we applied *ontology-driven conceptual modelling* to represent the occurrence of hazardous events and their relation to emergencies in situation-aware applications (Moreira, Ferreira Pires et al. 2017). The modelling languages used to specify these applications must support not only the design of structural aspects, but also temporal aspects and their relations (Costa, Mielke et al. 2012). Our ontology-driven conceptual modelling relies on ontological analysis based on UFO. Using UFO one can produce a well-founded core ontology that provides a precise definition of a specific field, being independent of a domain application (Scherp, Saathoff et al. 2011). This ontological approach supports common understanding among parties, addressing the semantic interoperability problem from the EWS specification to its implementation.

The SEMIoTICS framework also provides ontology alignments between the main standardized IoT ontologies (SSN/SOSA and SAREF), which can be used for semantic translations (Moreira, Daniele et al. 2017). OntoUML models have been incorporated in the SEMIoTICS core ontology[3], which is an extension of OntoEmerge (Ferreira, Moreira et al. 2015) that has alignments to other semantic models, such as the EDXL-CAP produced by the RESCUER project[4]. The SEMIoTICS core ontology represents the *Context Model*, which can be easily extended for specific application domains.

VALIDATION DESIGN

The validation design of SEMIoTICS included two activities: (1) developing an IoT EWS with a case study composed of emergency use cases as an instance of SEMIoTICS reference architecture; and (2) testing the IoT EWS developed by checking the fulfilment of each requirement.

Detecting accident risks with e-Health and logistics data

The INTER-IoT project developed a scenario to decrease the risk of fatal accidents at the port of Valencia. This scenario requires integration between logistics and health domains. The goal was to exploit how e-Health can use IoT platforms dedicated to logistics to prevent the occurrence of accidents and to support evacuation or attention in case of emergency situations (Ganzha, Paprzycki et al. 2016).

The main involved actor is the truck driver, who works for a haulier company that transports goods to/from the port. This company has a *haulier IoT platform* that tracks the trips made by the trucks and monitors the health of the drivers. The scenario features another IoT platform, the *port IoT platform*, for monitoring the data provided by the haulier IoT platform, integrating logistics and health data, and providing the emergency notifications to be consumed by the port emergency command centre. This emergency centre is simulated in two ways: (1) an UI based on Google Maps, able to plot the data in real-time; (2) a third-party partner provides an emergency management system that consumes data from the port IoT platform and integrates with the emergency notifications, being able to coordinate the emergency response. The scenario validation steps are described as functional and non-functional capabilities:

(IIOT-FC1) IoT platforms should be able to coordinate with emergency systems by detecting accidents and risks with trucks within the port area. The EWS should be able to identify vehicle collisions and severe changes of the driver's cardiac behaviour, alerting their urgency and severity to multiple targets through emergency interoperability standard(s).

(IIOT-FC2) The haulier IoT platform and the port IoT platform should be able to share cardiac information about the driver, monitored in real-time through an electrocardiography (ECG) device. The solution should be able to provide both raw and calculated data, e.g., ECG sequence (time series) and heart rate. These data need to be integrated such that the port emergency control system can consume them in conformance with emergency interoperability standard(s).

(IIOT-NFC1) IoT platforms should be semantically and syntactically interoperable. The solution should be able to integrate the involved IoT platform(s) in a way that their data syntax and semantics are understandable, i.e., can achieve common understanding among the participating parts.

(IIOT-NFC2) E-health and logistics should be integrated at the INTER-IoT application and semantics level, including primitives for data interpretation of medical and logistics data by using semantic models to represent e-health and logistics data within the IoT use cases (listed below).

[3] https://github.com/jonimoreira/SEMIoTICS
[4] http://fpc.ufba.br/ontologies/edxl_cap

(IIOT-NFC3) The energy consumption (battery level) of the devices being used for the situation identification mechanism should be monitored.

Use Cases and Situation Types

Four use cases were defined to validate these capabilities:

(IIOT-UC01) Vehicle collision detection

The EWS monitors the truck's instantaneous acceleration and location, being able to monitor the truck behaviour within the port area. The data are provided by both the mobile phone and by the ECG device, which enable the detection of possible vehicle collisions. Use cases like this are performed by using tri-axial (x, y, y) accelerometer sensor(s), deployed within the vehicle, to collect data about the vehicle's acceleration, allowing the calculation of the G-Force over time. The detection mechanism compares if the G-Force computed is above a certain threshold to detect a collision, which is usually 3G for devices deployed in the vehicle chassis and mobile accelerometer (Sulochana and Babu 2014). Collision detection is supported by computing the instantaneous cross-axial energy function (Equation 1) and comparing it to the threshold.

Equation 1:

$$CrossAxialEnergy = x^2 + y^2 + z'^2$$
$$z' = z - 1G$$

where *x, y, z* are axial accelerations measured in m/s^2. 1G = 9.806 m/s^2

The severity and urgency of the collision detected is calculated based on a deterministic distribution according to four ranges, as shown in Table 2. Variable *A* represents the cross-axial energy computed when the accident was detected, while variable *B* represents the threshold.

Table 2. Ranges of emergency severity and urgency

Range	Urgency	Severity	Colour
B < A <= B * 1.2	Minor	Expected	Green
B * 1.2 < A <= B * 1.4	Moderate	Immediate	Yellow
B * 1.4 < A <= B * 1.6	Severe	Immediate	Red
B * 1.6 < A	Extreme	Immediate	Black

In this use case, situation types are computed both at device and cloud levels, e.g., (UC01.ST01) collision detected based on one acceleration observation (from ECG unit) with cross-axial function and identification computed at the field gateway level; and (UC01.ST02) based on one acceleration observation (from ECG unit) with cross-axial function and identification computed at the cloud level.

(IIOT-UC02) Cardiovascular risk detection

The EWS is able to detect occurrences of arrhythmia of truck drivers, issuing alerts according to the possible cardiovascular emergencies. By detecting cardiovascular emergencies with truck drivers, it is possible to reduce the risk of an accident at the port area. The EWS monitors the cardiac behaviour of the driver, tracking the heart rate during the trip within the port area. The heart rate data are provided by the ECG device as a processed measurement from a function, which measures the intervals between R waves from the QRS complex of the ECG time series. Both processed heart rate and raw ECG data are made available to the EWS, which must adhere to health data privacy best practices, complying to the EU General Data Protection Regulation (GDPR).

Thresholds used by the detection mechanism should be based on classifications to detect health risks, both regarding bradycardia and tachycardia[5]. For example, the heart rate below 50 bpm is a bradycardia and above 99 bpm is a tachycardia. The heart rate score reflects the urgency and severity levels of the situation, e.g., for heart rate of 115 bpm, the score is 2, similar to the classification of severity and urgency of the previous use case. Figure 2 illustrates a more complex pattern covered by the UC02.ST03 situation type, which is activated when three consecutive bradycardia (UC02.ST02) are detected within an interval of 20 seconds.

[5] http://www.mayoclinic.org/diseases-conditions/bradycardia/diagnosis-treatment/diagnosis/dxc-20321665

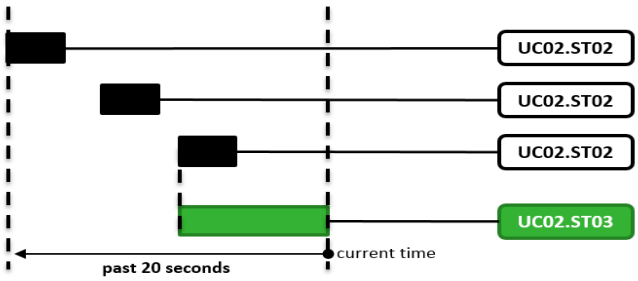


Figure 2. Complex event pattern that triggers the situation type UC02.ST03

(IIOT-UC03) *Correlation of vehicle collision and cardiovascular risks*

This use case exploits the possible temporal relations between UC01 and UC02 for detecting accidents that involve both collision and cardiovascular risk detection. This approach identifies that a collision is followed by an arrhythmia, which can represent a possible injury of the driver after the accident occurrence, as well as the other way around, i.e., an arrhythmia followed by a collision, which can represent that the accident occurred because of a health issue. For example, if a truck collision is detected from the mobile accelerometer data (UC01_ST03) and within 20 seconds a bradycardia is detected (UC02.ST01), then there is a high probability that the driver is injured and requires urgent medical support. This use case demonstrates the integration of both data sources and how to execute complex behaviours that rely on temporal relationships. The situation types defined for this use case include (UC03.ST01) collision followed by bradycardia within an interval of 20 seconds.

(IIOT-UC04) *Accident involving dangerous goods*

This use case extends UC01, UC02 and UC03 by monitoring the type of goods being transported (logistics data), taking into account the dangerous goods classification of the United Nations Economic Commission for Europe (UNECE): Explosives, Gases, Flammable liquids, Flammable solids (substances liable to spontaneous combustion; substances which, on contact with water, emit flammable gases), Oxidizing substances and organic peroxides, Toxic and infectious substances, Radioactive material, Corrosive substances, Miscellaneous dangerous substances and articles, hazardous substances. When detecting an emergency, the IoT EWS informs the type of dangerous goods being transported, warning the need of adequate equipment to deal with the material transported for effective response. This use case demonstrates the integration of data from both domains (health and logistics). Three situation types were defined for this use case according to each prior use case: (UC04.ST01-3) vehicle collision, cardiovascular risk, and vehicle collision with cardiovascular risk, respectively, with dangerous goods being transported, informed by the mobile app.

VALIDATION RESULTS

To tackle the three main challenges for semantic interoperable IoT EWS and to implement the envisioned INTER-IoT use cases, we developed the INTER-IoT-EWS[6] solution. INTER-IoT-EWS enables semantic data streaming with standardized ontologies serialized as JSON-LD, improving existing solutions for vehicle tracking and ECG monitoring.

Reusing Solutions: Vehicle Tracking and Real-Time Electrocardiogram (ECG) Monitoring

Many open source IoT solutions are able to track vehicle trips. We chose to apply the *MyDriving* solution discussed before to reduce the development time of INTER-IoT-EWS. The *MyDriving* architecture adheres to the SEMIoTICS framework. It uses a cloud gateway (*IoT Hub*) to broker data provided by IoT devices. The field gateway (*MyDriving* mobile app) provides data as JSON messages and, thus, can benefit from JSON-LD to serialize RDF for brokering semantic data. The main idea was to change *MyDriving* data interfaces, using specific ontologies to represent both logistics and e-Health. The *MyDriving* Android application, the *IoT Hub* and the application service with its database service were reused.

Real-time outpatient ECG monitoring is known as mobile cardiac telemetry and can stream data continuously to caregivers. Mobile cardiac telemetry is leveraged by IoT technologies, which offer opportunities to abnormal situation detection with support of medical wearables and cloud infrastructure. Modern ECG units can transmit

[6] https://github.com/jonimoreira/INTER-IoT-EWS/

the records of the electrical signals measured from the skin through wireless communication (e.g., Bluetooth), and are becoming smaller, more comfortable and energy-efficient. There are several examples of industry-oriented four-lead ECG devices for real-time outpatient monitoring, such as Shimmer3 ECG[7], and advanced stick-on ECG devices. To the best of our knowledge, none of the ECG monitoring solutions support real-time semantic data streaming, which became necessary due to the combination of requirements IIOT-FC2 (monitoring real-time ECG) and IIOT-NFC2 (e-Health semantic model).

A study was performed to select an industry-oriented four-lead ECG device for real-time outpatient monitoring. The main characteristics needed were: (1) to be a recognized and affordable solution (less than 800 EUR) and a reliable four-lead ECG for outpatient-monitoring; (2) to record high-frequency, e.g. 256/516Hz; and (3) to provide configurable sensor module and open-source API for data acquisition in a mobile environment. Shimmer3 ECG covers all these needs and was developed with the same technology as the *MyDriving* mobile app. Shimmer3 ECG has high accuracy and usability, being able to transmit data from the ECG device to a mobile phone application (Android) through Bluetooth. In addition, the Shimmer3 ECG solution provides an API for mobile environment with implementation examples, including the *ShimmerCapture*[8] mobile app (Android). Therefore, Simmer3 ECG solution was chosen to be integrated with *MyDriving*, playing the role of health data provider, requiring an e-Health ontology. Both logistics and e-Health ontologies require to be integrated with an IoT ontology such as SAREF or SSN/SOSA.

INTER-IoT-EWS Solution Architecture

The *MyDriving-LD* app along with the Shimmer3 ECG device represents the haulier IoT platform. Since the *MyDriving* app does not represent data as RDF, changes in the mobile app were required to transform the app to a *MyDriving for Linked Data* (*MyDriving-LD*). MyDriving-LD plays the role of the *Semantic Field Gateway* component of SEMIoTICS, providing logistics data, thus, requiring an ontology that represents transports, trips, location, acceleration and the goods transported. The *MyDriving-LD* should be integrated with the Shimmer3 ECG device, using the *ShimmerCapture* solution as example. For health data, we developed a SAREF extension called SAREF4health (Moreira, Pires et al. 2018), and for logistics data, we used the ontology modules developed by TNO[9] (LogiCO/LogiServ/LogiTran).

The cloud components (*Input* and *Output Handlers*, *Context Data*, *Situation Identification* and *Reaction Manager*) implement the accidents detection and warning brokering mechanism. Processing vehicle collision (IIOT-UC01) and hazardous health changes (IIOT-UC02) are performed at the cloud level, where the EWS implements the situation identification mechanism, including the composition use cases (IIOT-UC03 and IIOT-UC04). The solution also performs situation identification at device level, such as UC01-ST01.

Figure 3 shows the solution architecture. The Shimmer3 ECG device collects data from the truck driver and sends them to the *MyDriving-LD* application, aggregating and publishing JSON-LD messages in the *IoT Hub* (in the cloud). *Input Handler* subscribes to receive all messages published in *IoT Hub*, checking the TBox of each message, whether the domain is IoT or e-health or logistics, and checks if semantic translations are necessary to harmonize the data with the SEMIoTICS core ontology. If so, *Input Handler* requests the translations from IPSM, forwarding the input message and the alignment required (pre-configured) for executing the translations. The IPSM is responsible for syntactically and semantically translating the data streams: from JSON-LD to the INTER-IoT JSON-LD syntax, which is a structured JSON-LD with middleware (INTER-MW) information. Our INTER-IoT-EWS solution also provides an internal translation mechanism, which is a standard approach using SPARQL to query input data harmonizing it with the context model.

The syntactical translation mechanism for *sosa:Observation* objects creates observation instances according to the measurement property. For example, if the property is the vehicle collision computed by the ECG device or the mobile, then the method creates a *semiotics:VehicleCollisionDetectedObservation* instance, adding this translated observation to the ordered list of observations (according to the observation timestamp) that are sent as events to the CEP processor. After executing the translations, the *Input Handler* sends the non-structured ("raw" JSON-LD) data to *Context Data Manager*, and the structured data are represented as object-oriented classes, such as Plain Old C# Object (POCO) classes implemented by *Situation Identification Manager*, exposed through microservices. *Context Data Manager* annotates the data with the core ontology terms, providing heavyweight semantics by adding predicates from the foundational ontologies, storing the data in two ways: (1) inserting the JSON-LD messages in a document-based (NoSQL) database (MongoDB) for historical data storage; and (2) inserting the RDF in a triplestore (Virtuoso) for querying semantic data.

[7] http://www.shimmersensing.com/products/ecg-development-kit
[8] http://www.shimmersensing.com/products/shimmercapture-for-android
[9] https://www.tno.nl/en/

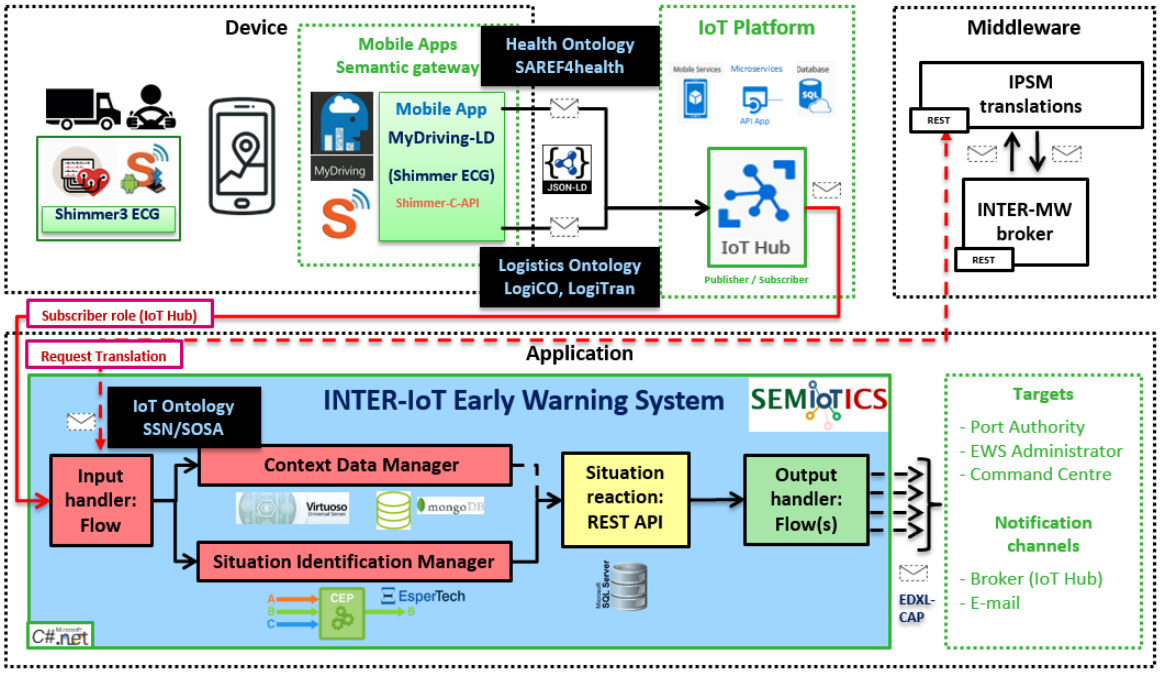


Figure 3. Solution architecture of the IoT EWS to detect accident risks and accidents

INTER-IoT-EWS is also aligned to the *MyDriving* architecture in terms of real-data handling ("hot path") and historical data handling ("cold path"). Both real-time data and historical data are used by the *Situation Identification* component, which was implemented with NESPER event processing server[10], taking advantage of the SQL-like approach of Event Processing Language (EPL)[11]. Therefore, *Situation Types Rules* are implemented as EPL statements, which uses the POCO classes as internal data model. Each *Situation Type Rule* is linked to a response process, i.e., the specific workflow to be executed once a situation is identified. When the CEP server identifies a situation type by matching the EPL pattern, the CEP server triggers an event handler method, forwarding the data to *Situation Reaction Manager*, which executes the workflow that includes the activities (tasks) for message brokering. *Situation Reaction Manager* checks the information requirements of each alert target, passing this information to *Output Handler* when a brokering message activity is executed. *Output Handler* is responsible for transforming the data to semantically compliant EDXL messages, brokering the notifications as JSON-LD messages. An UI application shows the alerts issued by the EWS with its severity, urgency and other information.

Laboratory Tests and Pilot in the Port

The validation plan checked whether the requirements were realized. The functional validation activities included factory acceptance tests (FAT) and site acceptance tests (SAT) through a pilot in the port of Valencia, where accidents were simulated in accordance with the port emergency exercises. Both FAT and SAT assess whether the system works for the intended risks' detection and warnings. FAT were performed to check completeness and requirements verification, simulating each of the situation types of each use case. Test hooks included data injection to increase the instantaneous acceleration data for the collision detection and to change the processed heart rate to below the bradycardia threshold and above the tachycardia threshold, as well as other more complex data patterns. Figure 4 shows a screenshot of the UI prototype we developed to perform the tests, with some results from the execution of emergency exercises in the port.

In total, 44 test cases were performed, of which 43 have been successful (97.7% test coverage). IIOT-FC1 was realized, since INTER-IoT-EWS enables an IoT platform (Azure IoT) to interoperate with emergency systems through the most appropriate interoperability standards for input data, through SSN/SOSA or SAREF, and for emergency notification, through EDXL-CAP. IIOT-FC2 was covered by the haulier IoT platform providing cardiac data of drivers in real-time, both raw ECG and processed heart rate data being available through a context broker (IoT Hub). Identification of cardiac issues was covered by the arrhythmia situation types. IIOT-NFC1 was covered by addressing both syntactic and semantic interoperability in the INTER-IoT-EWS component. Semantic interoperability was improved by the adoption of the standardized ontologies and, in

[10] https://github.com/espertechinc/nesper
[11] http://www.espertech.com/esper/

particular, the development of SAREF4health (Moreira, Pires et al. 2018). Syntactic interoperability was covered by the adoption of JSON-LD, while semantic translations were tested using two approaches, the "raw" SPARQL (internal to INTER-IoT-EWS) and IPSM (external to INTER-IoT-EWS). IIOT-NFC2 was also covered by the integration of the health and the logistics ontologies at application level. Finally, IIOT-NFC3 was covered since the battery level of the ECG device was provided (in real-time) to the EWS.

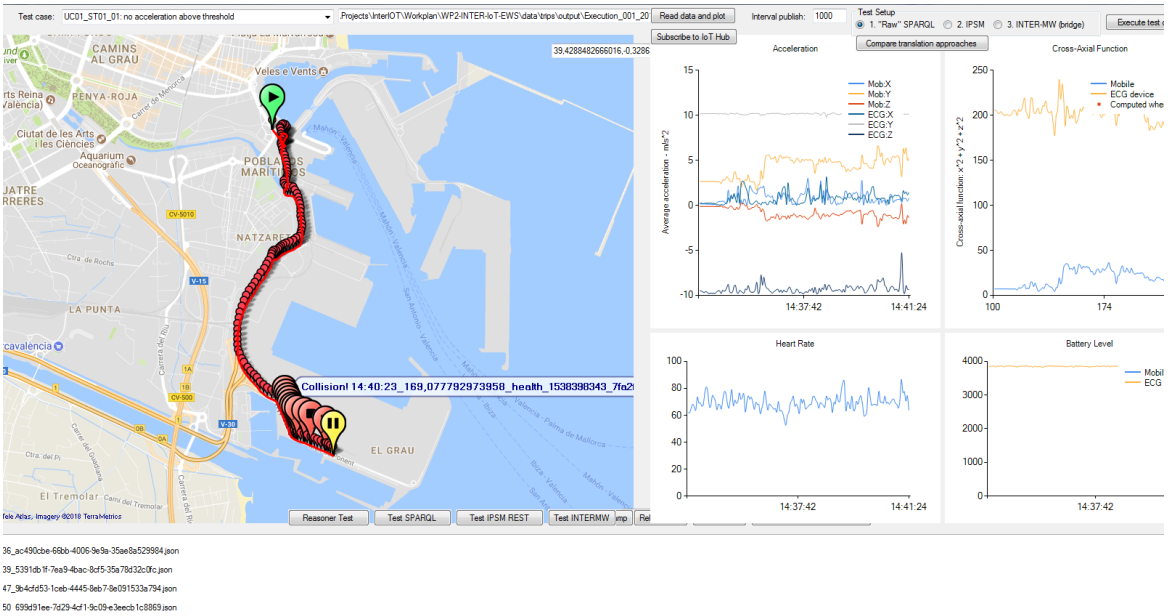


Figure 4. UI prototype simulating a command centre receiving data at real-time (tests in the port of Valencia)

This overall validation showed that SEMIoTICS can integrate data from different sensor types described with different semantic models, addressing Req2. It also enables data acquisition using semantic technologies (Req2) and addresses the integration of historical data with real-time data (Req3).

Performance Analysis

The performance validation showed that SEMIoTICS can address the processing time (Req4) and the scalability requirements (Req5), being able to change the situation types at runtime (Req6). The adoption of SML for specification and situation identification implementation with CEP technology, generated from SML to CEP transformations addressed Req7 and Req8. Personalized information requirements for the emergency notifications addressed Req9, allowing each target to configure the EDXL-CAP elements should be considered in the warnings received.

The overall INTER-IoT-EWS performance analysis included the measurement of the total transaction time for the whole EWS workflow. We followed a similar validation method of the *Semantic IoT EWS* approach for scalability and resilience: (1) test the upstream data acquisition and situation identification, measuring the total transaction time from *Input Handler* to *Situation Identification Manager* for each test setup; (2) validate data storage and query performed by *Context Data Manager*; (3) validate the multi-brokering multi-cluster approach, by investigating whether an industry-oriented cloud infrastructure, such as MS Azure, is able to multiply the throughput threshold of 700 msg/sec achieved by the Semantic IoT EWS applied for tsunami detection in the TRIDEC project (Middleton, Zlatev et al. 2013).

Storing the JSON-LD in MongoDB and querying data with JQuery showed to be extremely complex and inefficient, in terms of semantic features and total time. Since data are already formatted as RDF (JSON-LD), we tested storing the data in a Virtuoso server to benefit from SPARQL. In contrast with the MongoDB behaviour, the triplestore was slower for data insertion but efficient for querying. Therefore, for long-time historical data storage purposes, such as backup for audit, MongoDB seems to be the best option.

Concerning the efficiency of publishing semantically rich sensor data with a multi-broker approach similar to the *Semantic IoT EWS*, we conclude that the threshold of 700 msg/sec/unit, with message size of 6Kb, thus, 4.200 Kb/sec/unit, is easily reached with the Azure cloud infrastructure. According to the *IoT Hub* quotas and throttling[12], the throughput of publishing sensor data (termed "device-to-cloud") can reach 6.000 msg/sec/unit,

[12] https://docs.microsoft.com/en-us/azure/iot-hub/iot-hub-devguide-quotas-throttling

with message size of 4Kb, thus, 24.000 Kb/sec/unit. Therefore, the cloud infrastructure can scale up to five times the broker throughput of *Semantic IoT EWS* approach. Furthermore, Azure provides a limit of 50 brokers (*IoT Hub* instances) per subscription, thus, allowing a multi-broker approach deployed either in a single cluster (an Azure "resource group" deployment) or multiple clusters, as the federated cluster deployment.

We stress that the SEMIoTICS approach is even better because the *Semantic IoT EWS* approach splits data and metadata, separating the sensor data as key-pair values (serialized as XML messages) from the semantics (metadata), which is incorporated only on the server side (cloud level). In contrast, the SEMIoTICS provides a more efficient approach to enrich the semantics of sensor data at the field gateway level, which decouples the solution to the specific IoT platform and cloud infrastructures. However, this high efficiency has a high cost, namely €42,17 (unit/month). A crucial characteristic that impacts the performance and costs is the operating time requirement. Considering that the *MyDriving-LD* app publishes health messages (~30Kb) and logistics messages (~6Kb) each 3 seconds (12 Kb/sec), and each driver uses the solution for 8 hours/day, then each driver consumes ~42 Mb/h (337.5 Mb/day). The IoT Hub cost for a haulier company would be more €8,43 per driver per month.

CONCLUSION

Current IoT EWS approaches only partially address the semantic integration of a variety of data sources along with processing in time-critical applications and data analysis for effective responses. This paper describes the SEMIoTICS framework, which is a conceptual architecture for the development of interoperable IoT EWSs. The SEMIoTICS framework guides the use of different modelling languages, ontologies and IoT platform technologies towards the improvement of interoperability within and among IoT EWSs. The SEMIoTICS architecture combines different theories and technologies, such as ontology-driven conceptual modelling with foundational ontologies, Endsley's situation-awareness theory, IoT platforms, microservices architecture with JSON-LD, RDF implementation best practices for IoT, leveraged by the two main standardized IoT ontologies (W3C SSN/SOSA and ETSI SAREF) and their alignments for semantic integration with the most common standard for emergency systems (EDXL-CAP). SEMIoTICS was designed to be general enough for various types of emergency, and is not limited to a specific domain.

SEMIoTICS was validated through INTER-IoT-EWS, an instance of the SEMIoTICS reference architecture, in an emergency use case for the port of Valencia. INTER-IoT-EWS is able to monitor trucks delivering goods at the port and the drivers' vital signs, integrating logistics and health data for accident detection. The validation of INTER-IoT-EWS showed that SEMIoTICS is able to cover all identified requirements, enabling semantic integration of a distinct data sources with adequate processing performance and providing data analysis for effective responses with personalized warnings. The prototype test execution covered 97.7% of the test cases, the architecture showed to be scalable and perform better than the baseline.

The main disadvantage of SEMIoTICS is the high cloud infrastructure costs necessary to run the system with critical operating times. The framework also lacks a mechanism to cope with quality of information at the network level, such as a Grubbs' test for outlier detection.

REFERENCES

Balis, B., M. Kasztelnik, M. Bubak, T. Bartynski, T. Gubała, P. Nowakowski and J. Broekhuijsen (2011). "The UrbanFlood Common Information Space for Early Warning Systems." Procedia Computer Science **4**: 96-105.

Barros, R., P. Kislansky, L. Salvador, R. Almeida, M. Breyer, L. G. Pedraza and V. Vieira (2015). EDXL-RESCUER ontology: An update based on faceted taxonomy approach. CEUR Workshop Proceedings.

Battistini, A., A. Rosi, S. Segoni, D. Lagomarsino, F. Catani and N. Casagli (2017). "Validation of landslide hazard models using a semantic engine on online news." Applied Geography **82**: 59-65.

Chronaki, C. E., V. Kontoyiannis, D. Panagopoulos, D. G. Katehakis, D. Vourvahakis and K. Koutentaki-mountraki (2011). "Interoperability in Disaster Medicine and Emergency Management." Journal of Health Informatics **3**: 87-99.

Clinton, J., A. Zollo, A. Marmureanu, C. Zulfikar and S. Parolai (2016). "State-of-the art and future of earthquake early warning in the European region." Bulletin of Earthquake Engineering **14**(9): 2441-2458.

Costa, P. D., I. T. Mielke, I. Pereira and J. P. A. Almeida (2012). A Model-Driven Approach to Situations: Situation Modeling and Rule-Based Situation Detection. 16th International Enterprise Distributed Object Computing Conference (EDOC), IEEE**:** 154-163.

Dogac, A., Y. Kabak, A. Bulca, T. Namli and C. Erbas (2012). "RECONSURVE : JC3IEDM and EDXL based Emergency Management Service Oriented Architecture for Maritime Surveillance."

Du, C. and S. Zhu (2012). "Research on Urban Public Safety Emergency Management Early Warning System based on Technologies for the Internet of Things." Procedia Engineering **45**: 748-754.
Ferreira, M. I., J. L. R. Moreira, M. L. Campos, T. P. Sales, B. F. B. Braga, K. F. Cordeiro and M. Borges (2015). OntoEmergePlan: variability of emergency plans supported by a domain ontology. 12th International Conference on Information Systems for Crisis Response and Management (ISCRAM).
Ganzha, M., M. Paprzycki, W. Pawłowski, P. Szmeja and K. Wasielewska (2016). "Semantic interoperability in the Internet of Things: An overview from the INTER-IoT perspective." Journal of Network and Computer Applications.
Ganzha, M., M. Paprzycki, W. Pawłowski, P. Szmeja and K. Wasielewska (2017). Streaming semantic translations. 2017 21st International Conference on System Theory, Control and Computing (ICSTCC).
Keeney, H. J., S. Buan and L. Diamond (2012). Multi-Hazard Early Warning System of the United States National Weather Service. Institutional Partnerships in Multi-Hazard Early Warning Systems: A Compilation of Seven National Good Practices and Guiding Principles. M. Golnaraghi. Berlin, Heidelberg, Springer Berlin Heidelberg**:** 115-157.
Kim, J., S. Kang, J. Lee and B. W. Choi (2012). "A semantic translation method for data communication protocols." Journal of Systems and Software **85**(12): 2876-2898.
Lendholt, M., M. Á. Esbrí and M. Hammitzsch (2012). "Interlinking National Tsunami Early Warning Systems towards Ocean-Wide System-of-Systems Networks." Proceedings of the 9th International ISCRAM Conference - Vancouver, Canada(April): 1-10.
Middleton, S., Z. Zlatev, J. Mossgraber, F. Chaves and R. Tao (2013). The seven main challenges of an early warning system architecture. Information Systems for Crisis Response and Management (ISCRAM).
Moreira, J., L. F. Pires and M. V. Sinderen (2018). SAREF4health: IoT standard-based ontology-driven healthcare systems. 10th International Conference on Formal Ontology in Information Systems (FOIS 2018). Best paper award., Cape Town, South Africa.
Moreira, J., L. F. Pires and M. V. Sinderen (2018). Semantic interoperability of Early Warning Systems: a systematic literature review. Enterprise Interoperability IX: I-ESA proceedings. ICRIM workshop.
Moreira, J., L. F. Pires, M. V. Sinderen, R. Wieringa, P. Singh, P. D. Costa and M. Llop (2018). Improving the semantic interoperability of IoT Early Warning Systems: the Port of Valencia use case. Enterprise Interoperability IX: I-ESA proceedings.
Moreira, J. L. R., L. M. Daniele, L. F. Pires, M. V. Sinderen, K. Wasielewska, P. Szmeja, W. Pawlowski, M. Ganzha and M. Paprzycki (2017). Towards IoT platforms' integration: Semantic Translations between W3C SSN and ETSI SAREF. Semantics. Workshop SIS-IoT.
Moreira, J. L. R., L. Ferreira Pires, M. V. Sinderen and P. D. Costa (2017). Ontology-driven Conceptual Modeling for Early Warning Systems: Redesigning the Situation Modeling Language. MODELSWARD**:** 467-477.
Moreira, J. L. R., L. Ferreira Pires, M. v. Sinderen and P. Dockhorn Costa (2015). "Towards ontology-driven situation-aware disaster management." Journal of applied ontology **10**(3-4): 339-353.
Poslad, S., S. E. Middleton, F. Chaves, R. Tao, O. Necmioglu and U. Bugel (2015). "A Semantic IoT Early Warning System for Natural Environment Crisis Management." IEEE Transactions on Emerging Topics in Computing **3**(2): 246-257.
Poulymenopoulou, M., F. Malamateniou and G. Vassilacopoulos (2012). "Emergency Healthcare Process Automation Using Mobile Computing and Cloud Services." Journal of Medical Systems **36**(5): 3233-3241.
Roy, C., S. K. Sarkar, J. Åberg and R. Kovordanyi (2015). "The current cyclone early warning system in Bangladesh: Providers' and receivers' views." International Journal of Disaster Risk Reduction **12**: 285-299.
Scherp, A., C. Saathoff, T. Franz and S. Staab (2011). "Designing core ontologies." Journal of Applied Ontology **6**: 177-221.
Sulochana, B. and B. A. S. M. Babu (2014). "Monitoring and Detecting Vehicle Based On Accelerometer and MEMS Using GSM and GPS Technologies." International Journal of Computer Science Trends and Technology (IJCST) **2**(4): 55-59.
UNISDR (2015). Sendai Framework for Disaster Risk Reduction 2015 - 2030. United Nations International Strategy for Disaster Reduction.
Wächter, J. and T. Usländer (2014). The Role of Information and Communication Technology in the Development of Early Warning Systems for Geological Disasters: The Tsunami Show Case. Early Warning for Geological Disasters: Scientific Methods and Current Practice. F. Wenzel and J. Zschau. Berlin, Heidelberg, Springer Berlin Heidelberg**:** 227-252.
Waidyanatha, N. (2010). "Towards a typology of integrated functional early warning systems." International Journal of Critical Infrastructures **6**: 31-51.

Generating Crisis Situation by Using Ontology and Fuzzy Theory

Sammy TEFFALI
ICD, University of Technology of Troyes, Troyes, France
sammy.teffali@utt.fr

Nada MATTA
ICD, University of Technology of Troyes, Troyes, France
nada.matta@utt.fr

Eric CHATELET
ICD, University of Technology of Troyes, Troyes, France
eric.chatelet@utt.fr

ABSTRACT

A crisis is a complex situation, difficult to manage by the actors. Some of them are under stress it is difficult to deal with problems when consequences cannot be predict. The human conditions (concerning familial and life) and, the influence of the environment related to politics, economic, and media pushe the actors to lose control of the crisis situation. The question we face in this paper is: "is it possible to use the fuzzy theory for predicting the stress impact in crisis?" Our main hypothesis to represent experience feedback in a situation prediction in order to show negative consequences and correctness actions is taken account. Fuzzy theory concept is used in prediction in order to generate several situations.

Keywords

Crisis management, Fuzzy Theory, Ontology, Collaboration, Stress.

INTRODUCTION

A crisis situation generates a collective stress. This kind of situation request an organization to manage it and, to make pertinent decisions with the aim to reduce the effects in a short time with minimal damage. This paper shows us, how is possible to generate a predict stress impact situation by using fuzzy sets and knowledge management. This can help crisis management actors to learn by exploring different situations due to stress impacts. So, the main questions can be: Is it possible to use the ontology in the prediction of the impact of the stress during a crisis situation? Is it possible to use the fuzzy theory for predicting the stress impact situation in crisis? In this paper, some answers to this question are explored, especially, the generation of the stress impact situations by using the experience feedback and the fuzzy theory. Firstly, a description of the uncertainty and the fuzzy theory were addressed. Then, the crisis management as a collaborative situation and the impact of the stress during the crisis that can generate some uncertainty situations is studied. Also, an otology is identified for our study. And then, the use of the fuzzy theory in the representation of the stress impact during a crisis situation is discussed and a representation of the structure of the fuzzy generator called "NOE" is proposed.

THE FUZZY THEORY AS UNCERTAIN REASONING TOOLS

The uncertainty is a situation of inadequate information. It can be of three sorts: inexactness, unreliability, and borders with ignorance (Funtowicz, Ravetz 1990). For Zadeh, "Uncertainty is an attribute of information" (Zadeh 1997). It can prevail in situations where a lot of information is available (Van Asselt, Rotmans 2002). A new information or knowledge can decrease or increase the uncertainty. Some researchers suggest that uncertainty may be an important mediator of the impact of role stressors on the stress (Beehr 2000; Beehr, Bhagat 1985; O'Driscoll, Beehr 1994). The uncertainty concern all phenomena or systems whose behavior is generally disordered and irregular, which can often appear unpredictable and random.

Fuzzy Theory Principles

It is a mathematical theory of Zadeh (Zadeh 1996) based on intuitive reasoning. This theory considers the subjectivity and the imprecision. It may treat digital literacy; non-measurable values and for a linguistic issue (Bouchon-Meunier, Yager, Zadeh 1995). Fuzzy sets provide techniques to represent subjective and uncertain reasoning. Its goal is to build a formal system that it can make a qualitative reasoning (Rosental 2004). The fuzzy sets are used in different domains like pattern recognition, robotics, biology, economy, medicine, ecology, etc. (Zimmermann 2010). From this theory, we used the linguistic modifiers for using adverbs. The linguistic modifier permeate to attenuate or amplify the initial meaning of a number of attributes by the action of adverbs such as: very, more, at least, slightly. And, we use the multi-objective decision-making. It involves a selection of one alternative from a universe of alternatives given a set of criteria or objectives. For this study, we seek a decision that simultaneously satisfies all of the decision objectives.

THE CRISIS MANAGEMENT AS COLLABORATIVE ACTIVITY

During a crisis management, actors come from different organizations. They work, communicate, cooperate, coordinate and, exchange their own experiences. Their main common objective is how to deal with the crisis for reducing its effect? In this relationship, is noted that multiple actors are interdependent in their work. They interact each other to improve the state of their common field. They use resources like computers; plans; procedures; schemes; etc. This distributed activity can be represented as Triple C (Communication, Coordination, Cooperation). Several papers in the literature mention the role of Triple C in crisis management, and their interdependence (Martin, Nolte, Vitolo 2016). The interdependence of the 3C is affected by the regulation. Indeed, the regulation adjusting consists of sending or to receiving information, giving a warning (Communication); using means (Coordination); and to use the procedure, decision and organization (Cooperation).

REPRESENTING CRISIS SITUATION BY USING ONTOLOGY

Ontology is generally defined as a conceptualization of entities used in a specific domain (Gruber 1995). There are three levels of ontologies: Top, domain and applications (Guarino 1998). Identifying different concepts that represent crisis situations is needed before dealing with uncertainty in this type of situation. Related ontologies are then studied in this aim. For our study we choice the ontology named ResOnt (CHEHADE, Samer; Matta, Nada; POTHIN, Jean-Batiste; COGRANNE 2018) for rescue operations. In these ontologies, entities like tasks, actors, roles, organizations, materials, infrastructures are defined. These entities are specialized to answer our specific needs: representing main factors that influence uncertainty in crisis situations. Firstly, physical objects are distinguished from mental ones as recommended in top-level Ontology as Dolce (Guarino 1998) and SUMO (Niles, Pease 2001).

- Physical Objects emphasize Means, Persons, etc. (Fig. 1)
- Mental Constructs specify Task, roles, Influence, etc. (**Erreur ! Source du renvoi introuvable.**)

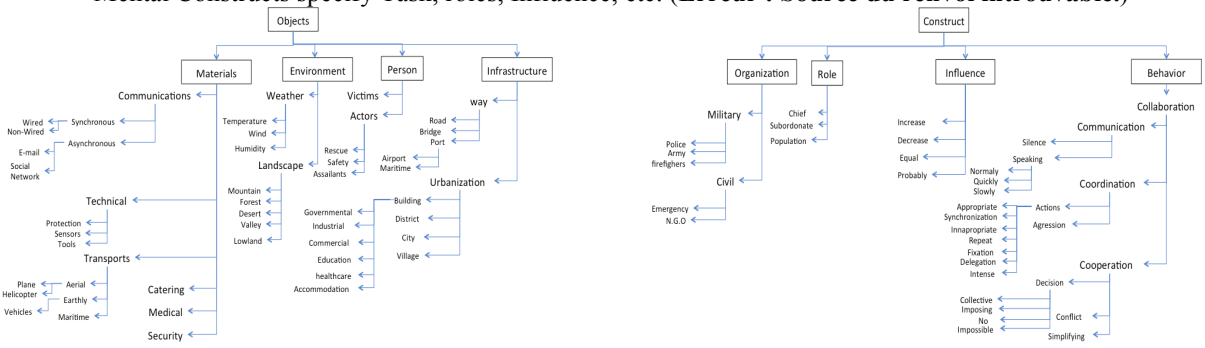


Fig. 1. Physical Object and Mental construct Ontology

Relationships between these concepts are then identified in order to reflect the dynamicity of crisis situations. Sediri propose to represent this dynamicity using state and events (Sediri, Matta, Loriette, Hugerot 2013). Crisis situations can be then seen as a sequence of events modifying states (0).

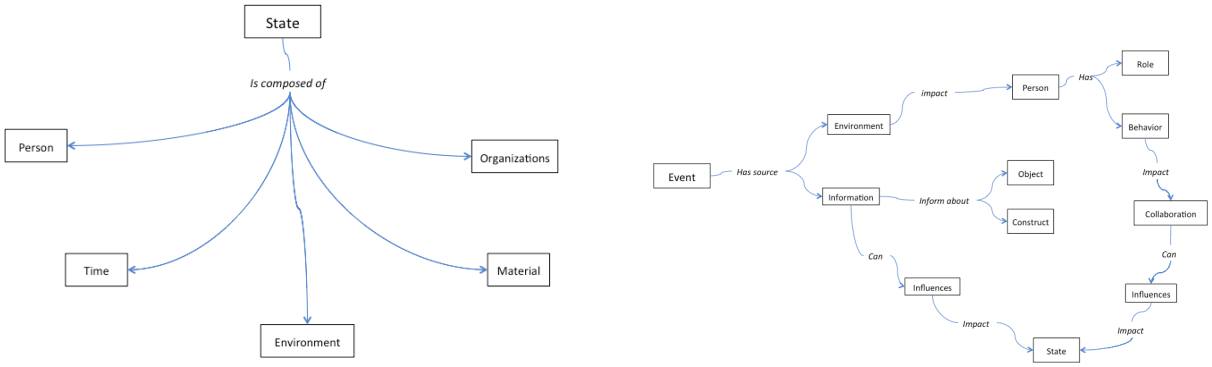


Fig. 2. State and Event relationships

These relationships are used in "NOE" situation generator that we defined (Teffali Sammy; Matta Nada; Chatelet Eric 2018). It is based on fuzzy theory.

APPLICATION ON STRESS IMPACT DURING A CRISIS MANAGEMENT

The Stress

The stress is an important factor in the success or the failure of the decision-making in a situation of crisis management. It is a particular relation between an actor and his specific environment. Its evaluation can be weak or exceed the actor resources and can be endangered his well-being (Lazarus, Folkman 1984). It was noticed that "Some policymakers reveal resourcefulness in crisis situations seldom seen in their day-to-day activities; others appear erratic, devoid of sound judgment, and disconnected" (Hermann 1979). Several approaches for the stress have been proposed, in the case of this study, the transactional approach is chosen (Cox, Griffiths, Rial-González 2000). It is related to cognitive and emotional processes, which gives interaction between a person and his environment (Boswell, Olson-Buchanan, LePine 2004). This indicates that the individual and the demand are two components. Indeed, an actor possesses personal characteristics that differentiate him from others. He is under the influence of environmental variables. He uses the coping. Lazarus defined the coping as "the overall cognitive and behavioral efforts, continuously changing, deployed by an actor for managing specific internal and/or external requirements, which are evaluated as consuming or exceeding his resource" (Lazarus, Folkman 1984). There are different studies that propose training and mental preparation methods to help actors to face the stress in crisis management (Ducrocq, Vaiva, Cottencin, Molenda, Bailly 2000; Pauchant, Mitroff, Lagadec 1991). This paper focus on the impact of stress on decision-making in order to promote learning from fails and guides based on experience feedback.

The Stress Impact During a Crisis

Boswel present four classes of indicators that influence stress conditions (Boswell, Olson-Buchanan, LePine 2004). (1) Task conditions: workload, etc; (2) relational conditions: conflict, harassment, etc; (3) job conditions: Mobility, no promotion, etc; (4) interaction private/profession: husband, children, family, etc. Different observable indicators of the stress are considered in psychology as manifestations of stress. Some of these are mainly noted: Speech rhythm (Siegman, Pope 2016), repetition of expressions and words (Kasl, Mahl 1965), using specific words (Kasl, Mahl 1965) etc; super activity, inadequate movement (Dittmann 1962) etc; silence (Weintraub, Aronson 1967); ambivalence, self-confidence (Aronson, Weintraub 1972); hostility and aggression (Gottschalk, Winget, Gleser, Springer 1966); inappropriate behavior and actions (Mehrabian 1968a, 1968b). Other studies have shown some manifestations of stress impact on decision-making as: Situation and context simplification (Lazarus et al, 1966); fixation on one possibility without any flexibility and alternatives (De Rivera 1968); consulting several opinions without concluding on a decision (Cooper et al., 1988); imposing a decision without measuring the impact and the consequences (Holsti 1972); missing decision-making and actions (Schlenker, Miller 1977). In this work, some of these indicators that can be measured directly from crisis management actions feedback are selected: super activity and imposing decision without considering the impact; silence, missing decision and actions; speech rhythm, aggression, and conflict of opinions and decisions; simplification of the situation and inadequate means and actions. Based on this study of stress impact, an expert dealing with military crisis situations has been interviewed in order to identify the influence types related to stress impacts. Ontologies entities previously defined are used as a guide in these interviews; the experts are solicited to specialize these entities and especially relationships between events and states.

INTEGRATING ONTOLOGY IN FUZZY THEORY APPLICATION

The advantage of the fuzzy theory is to use the linguistic value and to give for this value a mathematical sense. The main characteristic of this theory is the quantification of the uncertainty. As we know, the human reasoning in different areas is based on uncertainty. One of our principal preoccupations is how to interpret the impact of the stress in crisis situations using the human behavior and reasoning. The preferred method is to use the natural language. This is most comprehensive and simplest to interpret it. Our proposition is so to use the natural expression or words with fuzzy theory and especially the fuzzy sets. For that, we used a real situation lived as a case studied to apply the fuzzy theory.

Architecture of the Stress Impact Generator

Considering all these components, and the fuzzy logic theory we imagined a fuzzy generator called "NOE" who can generate state by introducing event. In the beginning we feed all the components mentioned above in a knowledge base. The information contained in the event is introduced in the generator. By using the fuzzy theory and the knowledge base, "NOE" generates the output state. For the next phase of this study, we are going to give more precision about some components that will enable us to use this theory.
We define for the first time a number of the sets:

- A is a universe of three actions: $A = \{a_1, a_2, a_3\}$ (1)

  Where $a_1 = \text{Communication}; a_2 = \text{Coordination}; a_3 = \text{Cooperation}$

- B is a universe of n actors: $B = \{b_1, b_2, \dots, b_n\}$ (2)
- C is a universe r places: $C = \{c_1, c_2, \dots, c_r\}$ (3)
- D is a universe of j data:

D includes different kinds of information as weather (w); crisis-place (cp); victims (v); population (p); morphology-of-land (m); assailant (as): infrastructure (in); and crisis-situation (cs). Then the function D is represented as the intersection of r-tuples noted: $D(w_j, v_j, cp_j, v_j, p_j, m_j, as_j, in_j, cs_j)$ (4)

- F is the universe of q means : $F = \{f_1, f_2, \dots, f_q\}$ (5)
- T the set of I time : $T = \{t_1, t_2, \dots, t_i\}$ (6)
- The linguistic modifier is a set of atomic terms defined and in relation to the feedback experience of the expert: $G = \{\text{equal}, \text{increase}, \text{decrease}, \text{probably}, \}$ (7)
- The State is defined as a function composed by actors (b), place (c), means (f) and data (d).

$$\text{State} = \{(b_1, c_1, f_1, d_1), (b_2, c_2, f_2, d_2), \dots., (b_n, c_r, f_q, d_j)\} \quad (8)$$

- The function event is composed by the couple action (1) or data (4), and by actors (2).

$$\text{event} = \{(a \text{ or } d_1, b_1), (a \text{ or } d_2, b_2), \dots, (a \text{ or } d_j, b_n)\} \quad (9)$$

$$\text{For all } a \in \{a_1, a_2, a_3\}.$$

The objective is to define the impact-stress function O composed by the functions state (8), events (9), the sets of the time (6) and the linguistic modifier (7).

$$O = f(\text{state}, \text{event}, T, G) \quad (10)$$

By using the impact-stress function O we can generate several situations during a crisis situation.

"NOE" THE GENERATOR OF THE SITUATION

The generation of situations with "NOE" can be illustrated on a study of a real case.

Example of Stress Impact During a Crisis Situation

A real case is studied in a crisis management situation. The author's observation can reveal some aspects of the impact of the stress during this event. It also provides, a timeline for actors' reaction with a general view on errors committed, means used, the places where the event was reported and, different information and data known. For this, a retired officer of the Algerian Army has been interviewed (as an expert) about one of crisis situations he dealt with. This case is about a terrorist attack on two villages in the Algerian mountain. The case analysis shows us some impact of the stress: (I) Imposing a decision without measuring the impact and the consequences. (II) Repetition of expressions and words. (III) Silence, missing decision and actions. (IV) Simplification of the situation and inadequate means and actions.

Generate Situations From the Case Studied by Using "NOE"

For our study, we apply the generator "NOE" to the scenario cited upper. We observe how some data like victims, place, and assailants using the linguistic modifiers can change. These help the manager to have the best understanding of the situation and to take the best decision in managing the crisis situation. Applied the fuzzy generator on the same example, we can also note that for the same state and for the same action, communication (silence), the fuzzy generator can generate three situations (**Erreur ! Source du renvoi introuvable.**). Otherwise, for the same state we can use other actions and with the fuzzy generator, we can generate a considerable number of states.

CONCLUSIONS

The present study suggests a crisis situation predicts, which generate a number of states of crisis. This is based on the stress impact representation by using experience feedback during a crisis. An experience is presented and modeled as specialization of existing crisis management ontologies. Based on that, we answer the main question. A representation is illustrated in a real case study in order to verify its applicability. The predict system is based on the Fuzzy theory that helps to deal with uncertainty and dynamicity of situations. So, for the same state and for the same action, the predict-system can generate a variety of situations. The natural progression of this study is to implement "NOE" generator in a learning system. This can help the crisis manager to explore different situations of the crisis and discover stress consequences to deal with.

REFERENCES

Aronson, Harriet And Weintraub, Walter, 1972. Personal Adaptation As Reflected In Verbal Behavior. In: Studies In Dyadic Communication. Pergamon Press New York. P. 265–278.

Beehr, T, 2000. An Organizational Psychology Meta-Model Of Organizational Stress. Theories Of Occupational Stress. 2000.

Beehr, Terry A And Bhagat, Rabi S, 1985. Introduction To Human Stress And Cognition In Organizations. Human Stress And Cognition In Organizations. 1985. Vol. 3, P. 19.

Boswell, Wendy R, Olson-Buchanan, Julie B And Lepine, Marcie A, 2004. Relations Between Stress And Work Outcomes: The Role Of Felt Challenge, Job Control, And Psychological Strain. Journal Of Vocational Behavior. 2004. Vol. 64, No. 1, P. 165–181.

Bouchon-Meunier, Bernadette, Yager, Ronald R And Zadeh, Lotfi Asker, 1995. Fuzzy Logic And Soft Computing. World Scientific. Isbn 9810223455.

, Samer; Matta, Nada; Pothin, Jean-Batiste; Cogranne, Remi, 2018. Data Interpretation Support In Rescue Operations:Application For French Firefighters. In: Proceeding Of The 15th Acs/Ieee International Conference On Computer Systems And Applications Aiccsa 2018. 2018.

Cox, Tom, Griffiths, Amanda And Rial-González, Eusebio, 2000. Research On Work-Related Stress. European Communities. Isbn 9282892557. Null

De Rivera, Joseph, 1968. The Psychological Dimension Of Foreign Policy. Ce Merrill Pub. Co.

Dittmann, Allen T, 1962. The Relationship Between Body Movements And Moods In Interviews. Journal Of Consulting Psychology. 1962. Vol. 26, No. 5, P. 480.

Ducrocq, F, Vaiva, G, Cottencin, O, Molenda, S And Bailly, D, 2000. Post-Traumatic Stress, Post-Traumatic Depression And Major Depressive Episode: Literature. L'encephale. 2000. Vol. 27, No. 2, P. 159–168.

Funtowicz, Silvio O And Ravetz, Jerome R, 1990. Uncertainty And Quality In Science For Policy. Springer Science & Business Media. Isbn 0792307992.

Gottschalk, Louis A, Winget, Carolyn M, Gleser, Goldine C And Springer, Kayla J, 1966. The Measurement Of Emotional Changes During A Psychiatric Interview: A Working Model Toward Quantifying The Psychoanalytic Concept Of Affect. In: Methods Of Research In Psychotherapy. Springer. P. 93–126.

Gruber, Thomas R, 1995. Toward Principles For The Design Of Ontologies Used For Knowledge Sharing? International Journal Of Human-Computer Studies. 1995. Vol. 43, No. 5–6, P. 907–928.

Guarino, Nicola, 1998. Formal Ontology In Information Systems: Proceedings Of The First International Conference (Fois'98), June 6-8, Trento, Italy. Ios Press. Isbn 9051993994.

Hermann, Margaret G, 1979. Indicators Of Stress In Policymakers During Foreign Policy Crises. Political Psychology [Online]. 1979. Vol. 1, No. 1, P. 27–46. Doi 10.2307/3790849.

Holsti, Ole R, 1972. Crisis Escalation War. Mcgill-Queen's Press-Mqup. Isbn 077359423x.

Kasl, Stanislav V And Mahl, George F, 1965. The Relationship Of Disturbances And Hesitations In Spontaneous Speech To Anxiety. Journal Of Personality And Social Psychology. 1965. Vol. 1, No. 5, P. 425–433.

Lazarus, Richard S And Folkman, Susan, 1984. Stress, Appraisal, And Coping. Springer Publishing Company. Isbn 0826141927. Null

Martin, Eric, Nolte, Isabelle And Vitolo, Emma, 2016. The Four Cs Of Disaster Partnering: Communication, Cooperation, Coordination And Collaboration. Disasters. 2016. Vol. 40, No. 4, P. 621–643. Doi 10.1111/Disa.12173.

Mehrabian, Albert, 1968a. Relationship Of Attitude To Seated Posture, Orientation, And Distance. Journal Of Personality And Social Psychology. 1968. Vol. 10, No. 1, P. 26.

Mehrabian, Albert, 1968b. Inference Of Attitudes From The Posture, Orientation, And Distance Of A Communicator. Journal Of Consulting And Clinical Psychology. 1968. Vol. 32, No. 3, P. 296.

Niles, Ian And Pease, Adam, 2001. Towards A Standard Upper Ontology. In: Proceedings Of The International Conference On Formal Ontology In Information Systems-Volume 2001. Acm. 2001. P. 2–9. Isbn 1581133774.

O'driscoll, Michael P And Beehr, Terry A, 1994. Supervisor Behaviors, Role Stressors And Uncertainty As Predictors Of Personal Outcomes For Subordinates. Journal Of Organizational Behavior. 1994. Vol. 15, No. 2, P. 141–155.

Pauchant, Thierry C, Mitroff, Ian I And Lagadec, Patrick, 1991. Toward A Systemic Crisis Management Strategy: Learning From The Best Examples In The Us, Canada And France. Industrial Crisis Quarterly. 1991. Vol. 5, No. 3, P. 209–232.

Rosental, Claude, 2004. Fuzzyfying The World: Social Practices Of Showing The Properties Of Fuzzy Logic. Growing Explanations: Historical Perspectives On Recent Science. Duke University Press, Durham, Nc, Usa. 2004.

Schlenker, Barry R And Miller, Rowland S, 1977. Egocentrism In Groups: Self-Serving Biases Or Logical Information Processing? Journal Of Personality And Social Psychology. 1977. Vol. 35, No. 10, P. 755.

Sediri, Mohamed, Matta, Nada, Loriette, Sophie And Hugerot, Alain, 2013. Crisis Clever, A System For Supporting Crisis Managers. In: Proceedings Of Ieee, Acm, Proceeding Iscram, 10th Internationa Conference On Information Systems For Crisis Response And Management. Baden-Baden, Germany. 2013.

Siegman, Aron Wolfe And Pope, Benjamin, 2016. Studies In Dyadic Communication. Elsevier. Isbn 1483285286.

Teffali Sammy; Matta Nada; Chatelet Eric, 2018. Learning From Fails In Crisis Management: Case Of Stress Impact. Proceeding Of The 14th International Conference On Natural Computation, Fuzzy Systems And Knowledge Discovery. 2018.

Van Asselt, Marjolein B A And Rotmans, Jan, 2002. Uncertainty In Integrated Assessment Modelling. Climatic Change. 2002. Vol. 54, No. 1–2, P. 75–105.

Weintraub, Walter And Aronson, H, 1967. The Application Of Verbal Behavior Analysis To The Study Of Psychological Defense Mechanisms. Iv: Speech Pattern Associated With Depressive Behavior. The Journal Of Nervous And Mental Disease. 1967. Vol. 144, No. 1, P. 22–28.

Zadeh, Lotfi A, 1996. Fuzzy Sets. In: Fuzzy Sets, Fuzzy Logic, And Fuzzy Systems: Selected Papers By Lotfi A Zadeh. World Scientific. P. 394–432.

Zadeh, Lotfi A, 1997. Toward A Theory Of Fuzzy Information Granulation And Its Centrality In Human Reasoning And Fuzzy Logic. Fuzzy Sets And Systems. 1997. Vol. 90, No. 2, P. 111–127.

Zimmermann, H□J, 2010. Fuzzy Set Theory. Wiley Interdisciplinary Reviews: Computational Statistics. 2010. Vol. 2, No. 3, P. 317–332.

Situation Representation and Awareness for Rescue Operations

Samer CHEHADE
Department of Research and Development
DataHertz
Troyes, France
Samer.chehade@datahertz.fr

Nada MATTA
Institut Charles Delaunay, TechCICO
Université de Technologie de Troyes
Troyes, France
Nada.matta@utt.fr

Jean-Baptiste POTHIN
Department of Research and Development
DataHertz
Troyes, France
Jean-baptiste.pothin@datahertz.fr

Remi COGRANNE
Institut Charles Delaunay, LM2S
Université de Technologie de Troyes
Troyes, France
Remi.cogranne@utt.fr

ABSTRACT

During rescue operations, being aware of the situation is very critical for rescuers and decision-makers to reduce the impacts. This work aims to support situation awareness amongst actors participating in rescue operations by adopting an ontology-based approach. An application ontology is proposed based on existing related ontologies and operational expertise collection. It will help to ensure common situation representation and understanding between different actors. After that, a knowledge-based system will be developed and integrated in actors' environment to support decision-making. Our preliminary results are shown in this paper.

Keywords

Application Ontology, Common situation representation, Rescue of people, Situation awareness.

INTRODUCTION

Rescue of people consists in saving their life in case of particular situations by applying responsive operations. In France, it is described as precise duties to be achieved by several public services in order to ensure the protection of people by allowing them to escape from dangers, securing intervention sites, providing medical help, and finally, making sure the evacuation to an appropriate place of reception (Diederichs et al., 2006). These services have to deal with several flows of information coming from many sources. They have to make decisions based mainly on these information. They also have to cooperate and each one should be aware of actions and environment's perception ensured by the other even if they are not in the same place. A shared situation representation between different involved actors is thus required. The aim of sharing a common situation representation between actors is to ensure situation awareness.

Semantic representation techniques (Sowa, 2000; Studer et al., 1998) and ontologies (Gruber, 1993) can be very helpful in order firstly to represent main situations entities and then to guide situation's perception sharing between actors (Nunavath et al., 2016). In this paper, we present our work done toward the definition of an application ontology to represent rescue operations in France as well as information and data flow between actors. This ontology will help to share common situation representations between different actors. It responds to situation awareness requirements, which necessitate having a global vision of main elements, aspects and dimensions in a given situation. This paper is divided in three sections:

1. Definition of rescue operations and actors involved in France
2. Situation awareness and rescue operations
3. Ontology for situation representation, a methodology to build it and related existing ontologies

RESCUE OF PEOPLE

Also called emergency rescue, *rescue of people* is one mission of medical services and firefighters. It consists in ensuring the safety of victims and patients by making them able to escape from a danger, sending adapted means and securing interventions sites, applying first aid gestures, and, finally, ensuring the evacuation and transportation to a suitable place of reception. In France, two main services are engaged in rescue operations and emergency care to the population: Emergency Medical Assistance Services (SAMU) and Departmental Fire and Rescue Services (SDIS) (Diederichs et al., 2006). A common referential has been elaborated in order to make responsibilities clearer and delimit missions (Comité quadripartite DDSC et DHOS, 2008). The mission of SDIS is to ensure protection, prevention and firefighting. They are also responsible of the rescue of patients or victims of disasters and accidents as well as their evacuation (Chehade et al., 2018; Comité quadripartite DDSC et DHOS, 2008). Whereas, the mission of SAMU is limited to providing medical assistance in emergency situations. This task can be divided into five subtasks: 1) Provide permanent medical listening, 2) choose and trigger responses according to the nature of the calls, 3) make sure the disponibility of the means of hospitalization adapted to the patient's or victim's condition, 4) prepare victims transportation using a private transport company or another public service and, 5) make certain the victim's admission. Other centers and services also participate in rescue operations. They are attached to the two previous ones and are responsible of receiving alerts and calls, transferring received calls to the good actor as well as ensuring a good information exchange and communication between SDIS and SAMU. Each SDIS possesses Health and Medical Rescue Service (SSSM) that assists, in particular, in emergency relief missions. Moreover, it has a Fire and Rescue Departmental Operational Center (CODIS) responsible for coordinating the activity of fire and rescue services. Add to that, it has one or several Alert Processing Centers (CTA), responsible for receiving, reorienting and processing requests and alerts. On the other hand, each SAMU has a Center of Receiving and Regulating Calls (CRRA) responsible of receiving alerts and calls and transferring them to a SDIS when there is a need of participation of this latter in a rescue operation. They are also connected to Mobile Service of Emergency and Reanimation (SMUR), which provides care for victims or patients whose conditions require, urgently, special medical care.

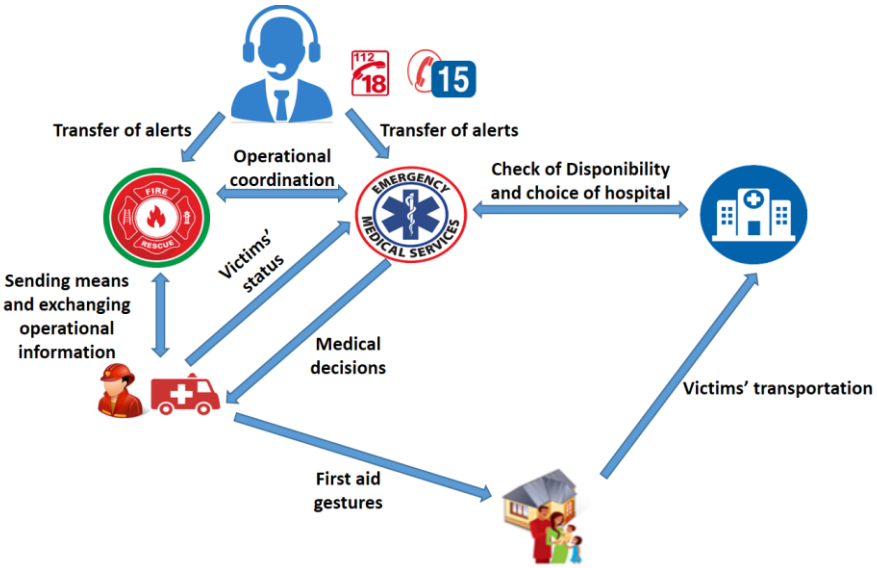


Figure 1. Involved actors and flow of information during rescue of people

An example illustrating the multiplicity of engaged actors during an operation is shown in Figure 1. In this example, we took the case of a medical rescue operation. As we can see, participating actors exchange a sheer volume of information such as operational information or victim's status. This plurality of sources and the important volume of exchanged information during an operation can lead to overcharge and make it challenging for actors to understand provider's intentions. Sharing situations' perception between actors can be important in order to solve this problem and ensure situation awareness. Ontologies can help in order to ensure sharing same perception of situations.

SITUATION AWARENESS

Nowadays, the term of situation awareness is widely used; it serves as a foundation of overall performance throughout many different domains, such as education, military operations, air traffic control, driving, search and rescue, and crisis management (Endsley, 2006). Endsley in (Endsley, 1995) defined it as *"the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the*

projection of their status in the near future". In addition, she defined steps to achieve human situational awareness and divided them into three levels. The first level of situation awareness is the perception of the situation elements, their status, their attributes, and their dynamics. After that, level two consists in the comprehension of the elements and the current situation. This comprehension depends on understanding the meaning of elements perceived in the first level as well as the relation between these elements and the objectives. Finally, the third level involves making predictions about the future status and actions of the situation elements based on the first two levels. From the above definition, we can say that situation awareness is the result of understanding of what is happening around us and is the basis for decision-making. Researchers in different areas have determined that expert decision-makers start with classifying and understanding a situation, and proceed then to decision making (Endsley, 2006; Kulyk et al., 2008). Furthermore, situation awareness has a vital importance in vital collaborative environments since it can improve team performance by improving the quality of made decisions (Endsley et al., 1995). Rescue domain is one of these environments.

Problems of Situation Awareness in Rescue Operations

In rescue operations, being aware of the situation is very important for cooperation of participating teams and decision makers in order to reduce negative impacts such as loss of a victim's life. However, ensuring a high degree of situation awareness is one of most difficult components of many jobs and one of the most vital and challenging duties for many rescue actors (Endsley, 2006). In fact, multiple actors coming from various organizations participate in a single operation as it was shown in Figure 1. These actors are from various backgrounds with distinct missions, experiences, expertises and goals. Thus, it is difficult for decision-makers to understand the situation perception of actors and other-decision makers. During a rescue operation, a large number of information is exchanged between actors during an operation. These actors have to interpret these information in order to develop an overall picture of the situation since their decisions are based on understanding the situation first. This interpretation can differ from an actor to another since they are from different backgrounds and are presents in different places. For example, a decision-maker has to make his/her decisions based on the received information from another actor and his understanding of the situation. S/he has to be aware of the exact situation because any misunderstanding of the situation can lead to its misinterpretation and thus to bad decisions and actions (Nunavath et al. 2016). Moreover, the dynamicity of situations and the continuous evolution of their status is another problematic in face of enhancing situation awareness. According to these problems, we decided to work on sharing a common situation representation and environment perception between different actors, which can lead to ameliorate awareness of the situations.

Related Work

In recent years, rescue operations and emergency responses have merged technologies of computer, communication, artificial intelligence, system engineering and knowledge engineering. These technologies aim to support the coordination, cooperation, communication and decision making of actors. Several systems and applications were developed recently in order to support information sharing and enhance situation awareness in critical and dynamic domains such as rescue operations and crisis management. Some researchers focused on studying situation awareness in robot-assisted rescue operations (Larochelle et al., 2011; Riley and Endsley, 2004) while others studied the effect of using mobile devices and tabletops in these operations (Bergstrand and Landgren, 2009; Engelbrecht et al., 2011).

On the other hand, research on ontology-based situation awareness has enormously increased during the past and current decades. Several ontology-based situation aware systems were successfully developed such as "AKTiveSA" (Smart et al., 2003) and "BeAware" (Baumgartner at al., 2010). An important number of studies confirm the importance of using ontologies in order to ensure this awareness (Kokar et al., 2009; Kokar and Endsley, 2012; Matheus et al., 2003). They also afford high-level ontologies to capture situation descriptions. These ontologies can be specified and contextualized in order to define more domain specific ones. Javed el al, (Javed et al., 2011) developed a system for enhancing shared and team situation awareness in emergency management domain by using ontologies. They created an ontology by extending the Core Ontology for Situation Awareness (Matheus et al., 2003). Authors in (Nunavath et al., 2016) proposed representing and sharing domain knowledge through domain model in order to support situation awareness. To do that, they developed an ontology in order to unify concepts between actors. However, their work was restricted to a specific kind of emergencies that is the fire building. Ashish et al, (Ashish et al., 2009) worked on situation representation in crisis management domain. The aim of this representation was to support situation awareness through the support of multiple applications such as monitoring, analyzing and planning. They based their work on event-based approach to represent the state and the evolution of crisis, the progress of response process, and the state of crisis site. To do that, they constructed an ontology and they proposed an *event management system* as a framework for representing

situations. However, it is limited since the representation depends on the occurrence of events and makes it difficult to represent all the required information such as the availability of resources or hospitals.

As discussed previously, we found that several ontologies have been defined in order to support situation awareness in crisis and emergency response domain. However, none of these ontologies covers all aspects, dimensions and elements in emergency management, which is necessary to ensure situation awareness and representation. Add to that, we did not find any ontology that aim to ensure situation awareness in traditional rescue operations. Based on this problematic, we propose to construct an ontology for representing situations during rescue operations. The principle objective of this ontology is to respond to situations awareness requirements. The first requirement of situation awareness is to have a global vision of a situation. In other words, this ontology take into consideration all aspects, elements and tasks in order to promote situations perception between different actors and to support situation awareness.

ONTOLOGY FOR COMMON SITUATION REPRESENTATION

As cited above, our aim is to build an application ontology related to rescue operations in France and to be more specific, to the organization, communications, responsibilities, flow of information and processes during a rescue operation. This ontology will be used for representing situations and sharing these representations between different actors. In this section, we give details about ontologies, their categories and the methodology we followed in order to construct the proposed ontology. This ontology will help to emphasize main elements to share between actors especially when operating and solving a problem. It will be used in communication and problem's perception support systems.

Definitions

Ontology is defined as *"an explicit specification of conceptualization"* (Gruber, 1993). Ontologies can serve on two levels: (1) as a vocabulary that makes use of appropriate terms to describe entities and agents of a domain, as well as interactions and relationships between them and (2) as a knowledge base for a particular domain. In rescue operations domain, ontology can grant a shared perception of a situation by actors. This reduces the chances of misunderstanding and the rescuers as well as decision-makers can fully understand the evolution of situations. Generally, there are three categories of ontologies. This classification depends on the level of generality of the ontology, and are separated into *application ontologies*, *domain ontologies*, or *generic ontologies*, also called *top-level ontologies*. Generic ontologies are domain independent. They contain general concepts such as action, space, time, object, event and many others that can be used in different domains. Examples of these ontologies are DOLCE defined by its authors as an ontology of particulars (Gangemi et al., 2003), the Suggested Upper Merged Ontology (SUMO) (Pease et al., 2002) and OpenCyc ontology (Matuszek et al., 2006). Domain ontologies are related to a specific domain such as rescue operations. They are specification of generic ontologies. A specification of domain ontologies can be done in order to construct application ontologies that describe specific concepts in a specific domain and specific associated tasks. Good examples of domain ontologies are that related to emergency response and crisis management domain (Li et al., 2008; Yu et al., 2008). Moreover, a huge number of application ontologies have been constructed from which we cite EDXL-RECUER (Barros et al., 2015), SHARE-ODS (Konstantopoulos et al., 2006), and EMERGEL ontology (Azcona, 2013) developed to support RESCUER (Villela et al., 2014), SHARE (Konstantopoulos et al., 2006; Velde et al., 2005), and DISASTER (Azcona, 2013; Schütte et al., 2013) projects respectively.

Methodology

To construct ontology, we adopted the methodology proposed by (Bachimont et al., 2002). This methodology consists of three main steps: Normalization, Formalization, and Operationalization. The advantage of this methodology is that it details steps to build the ontology starting from identifying units until having a complete ontology with rules and relations passing by structuring taxonomies.

Normalization

This step consists in identifying terms and units in a domain, extracting their meanings, giving complete definitions to these terms, and then expressing differences and similarities of each term or unit with respect to its parents and siblings. The result of this step is a first taxonomy of notions, which can be modified during the definition of properties and relations with other notions. This modification can occur in the Formalization step. In order to identify terms, a deep study of the domain is required. This study includes studying and analyzing the domain related documentation and conducting interviews with domain experts. Another key component in this step is to reuse other existing ontologies as much as possible since they may contain common concepts with their

definitions and relationships (Bouaud et al., 1995). To do that, we started by studying domain related documentation. In addition, we conducted an interview with a firefighter expert in France. The aim of this interview was to understand the organization and role of different actors and organizations. Questions turned on the different hierarchies of organizations, their roles and relations between them. We explored also the literature review about existing ontologies related to situation awareness and rescue operations domain.

During our literature review, we found and studied many ontologies defined in the domain of rescue operations. Some of these ontologies and not directly applicable in our case such as SHARE-ODS that does not cover all aspects in rescue operations (Konstantopoulos et al., 2006), while others are not publicly accessible. In addition, we found an ontology related to situation awareness that is the main interest of our work (Matheus et al., 2003). We also found several application and domain ontologies constructed in emergencies and crisis management domain. These ontologies cannot be used completely in our case because there is a difference between an ordinary rescue response and an emergency or crisis response. However, we used these ontologies as supports to borrow ideas and some defined concepts in order to build our ontology specific for rescue operations in France. In addition, many important concepts related to our particular context are not defined in previous ontologies. For instance, structures and actors organization, roles, dataflow, and many other concepts. From the ontologies that we found, we based our study on five ontologies that are the most applicable to our context. These ontologies are the emergency response ontology (Li et al., 2008), the emergency ontology (Yu et al., 2008), EMERGEL (Azcona, 2013), EXDL-RESCUER (Barros et al., 2015), and the situation awareness core ontology (SAW) (Matheus et al., 2003).

The first ontology we studied is the EMERGEL ontology (Azcona, 2013) defined in the context of the project "DISASTER" focusing on information exchange on a semantic level (Azcona, 2013; Schütte et al., 2013). It is an application ontology built to temporally describe a crisis or disaster situation. In order to construct this ontology, authors specified some generic classes defined in the top-level ontology DOLCE particulars (Gangemi et al., 2003). This ontology takes into consideration, **SPACE**, **TIME**, **OBJECTS** representing physical objects, **CONSTRUCTS** representing non-physical objects, and **ACTIVITIES** representing duties and missions to be achieved. Examples of concepts of this ontology are *Person*, *Equipment*, *Vehicle*, *Communication*, *SpatialPoint* and *Infrastructure*. The advantage of this ontology is that it covers different subjects in emergency response.

The second ontology we chose is the EXDL-RESCUER ontology (Barros et al., 2015) developed to support the project "RESCUER" designed to assist actors in emergencies by using crowdsourcing information (Villela et al., 2014). The aim of this application ontology is to construct a conceptual model corresponding to coordination and information exchange with other systems. It defines a group of message contexts and focuses on the type of exchanged data during an emergency. In this ontology, authors defined concepts correspondent to the type of exchanged messages such as Alert, MsgType, ResponseType, Info, etc.

The third ontology we consider is the emergency ontology constructed to enhance the reorganization of knowledge in decision-support systems (Yu et al., 2008). Authors developed this domain ontology by adopting the Activity First Methodology (Mizoguchi et al., 1995). This ontology contains four main classes: **EVENT** that can be a *disaster* or a *disease*, **SUBJECT** divided into *personal* and *actor*, **TASKS** consisting of *detection*, *prevention*, *rescue*, *evaluation* and *communication*, and **RESOURCE** that can be *artificial* and *inartificial*. Each class is also divided into several subclasses, each having many instances. We used this ontology since it gives the many general concepts that are in common between rescue operations and crisis management. This ontology has the advantage of covering multiple contexts in disaster response, ranging from events to tasks, passing by resources and subjects.

Moreover, we studied the 'Task Ontology' constructed in the aim of supporting the deployment of the evacuation planning system during emergencies (Li et al., 2008). This ontology defines a unique vocabulary usable by different actors and organizations regardless of the emergency nature. It defines four generic concepts that are Preparation, Response, Rescue, and Handling, divided each into several sub concepts. This ontology is restricted to the steps and tasks to achieve during an emergency. From this ontology, we reused some concepts that are in common with rescue operations such as communication, medical aid, and victim assistance.

Finally, we studied the core ontology for situation awareness (Matheus et al., 2003). Authors constructed this ontology as a reference for building ontologies for arbitrary situations. The generic concept defined in this ontology is **SITUATION** that is a collection of **SITUATIONOBJECTS**, **GOALS** and **RELATIONS**. SituationObjects represent entities in the world and they have attributes. One kind of SituationObjects is PhysicalObject. The main advantage of this ontology is that is takes into consideration the evolution of situations with respect to time and space. From this ontology, we reused several main concepts used for situation representation such as Situation, Time. However, we did not extend this ontology since it is a little bit specified to situation awareness and when we tried to extend it we were not able to cover all concepts and aspects in rescue operations. Another reason that prevented us from extending it is that there is a mix between Attributes, Relations and Properties and we cannot follow this mixing since we decided to use semantic networks for representations. Semantic Networks are one type of formalisms used for knowledge representation in which there is a difference and separation between an Is-a relation and other relations that are in general properties which makes inferences simpler (Sowa, 2008).

After studying the existing ontologies, the domain related documentation and conducting an interview with a firefighter expert, we identified notions. We gave then definitions and we classified these notions into a first taxonomy. We moved then to the next step: the ontology formalization.

Formalization

The second step is Formalization and consists in defining properties and relations between notions classified into the taxonomy obtained in the first step (Bachimont et al., 2002) and reorganizing this taxonomy in a way that it enables the addition of new concepts. At the end of this step, the taxonomy will become a true ontological tree and notions will become concepts with relations between them. To do that, we defined relations between concepts. However, we stayed with our relations at a high level without making relations between low-level concepts. The part related to relations and properties will be detailed in the Operationalization subsection.

Let us talk first about the main concepts and the final taxonomy of our ontology. First, we considered a rescue operation as an entity and we divided it into two generic concepts **OBJECTS** and **CONSTRUCTS** in order to make a first classification between different categories as it has been done in EMERGEL ontology (Azcona, 2013). These two categories represent physical and abstract defined in SUMO (Pease et al., 2002). We chose to follow the classification of SUMO since it is a top-level ontology that can ensure interoperability between lower level ontologies. **OBJECTS** are defined as a representation of physical objects in the real world. As shown in figure 2, the main category **OBJECTS** include three main concepts: *Environment, Persons and Material.* Each main concept contains several sub-concepts. *Environment* represents the context of operations. It contains Infrastructure that includes Ways, Ports and Buildings, Space that could be a Decision Space or an Intervention Site and Weather that is divided into Temperature, Wind and Humidity. *Person* represents people involved in a rescue operation. A person can be an Actor who is participating in an operation or a Victim who is being rescued. While in *Material*, we consider concepts concerning inartificial resources used during a rescue operation including Transport, Medical, Safety, Catering, Communication equipment and Technical equipment.

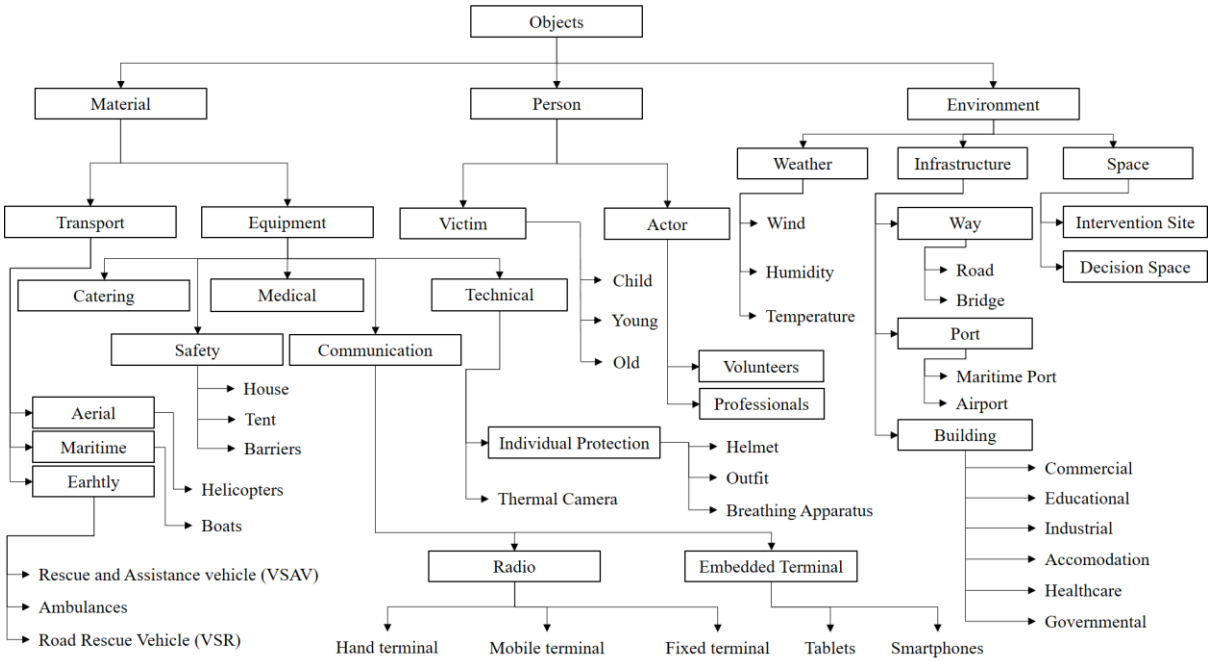


Figure 2. Hierarchy of Objects

On the other hand, **CONSTRUCTS** contain concepts related to non-physical objects. This category includes six main concepts that are *Tasks*, *Organization*, *Time*, *Characteristics*, *Data* and *Incident,* divided each into several sub-concepts as shown in Figure 3. *Organization* represents the organism involved in an operation. It can be a Military organization such as Army and Firefighters (SDIS) or a Civil organization such as medical services (SAMU) connected each to different centers. *Time* is used for sure since we talk about dynamic operations and situations and it contains Timeline. *Characteristics* are used to describe some objects and constructs. They are divided into main categories: Qualitative and Quantitative Characteristics. For example, Type and Form can characterize the exchanged Data. It can be a report in form of text. *Data* represents the exchanged information before, during and after an operation. It informs on situations and their evolution as well as occurring events during a situation. *Incident* represents the type of situation behind the intervention. It can be a disease, an accident, a fire or a natural event causing victims. Finally, *Tasks* represent the required missions and duties to ensure

effective operations. These tasks covers three main phases: 1) Preparation phase including tasks to be taken before an operation such as personal training and resources maintenance, 2) Response phase including tasks to be achieved during the operation such as Communication, Coordination, Cooperation and, 3) tasks to be taken at the end of the operation such as investigation, reporting and supplying social assistance to the victims. Due to a lack of space, we decided to represent the concepts related to Tasks in a separated figure of constructs as shown in Figure 4.

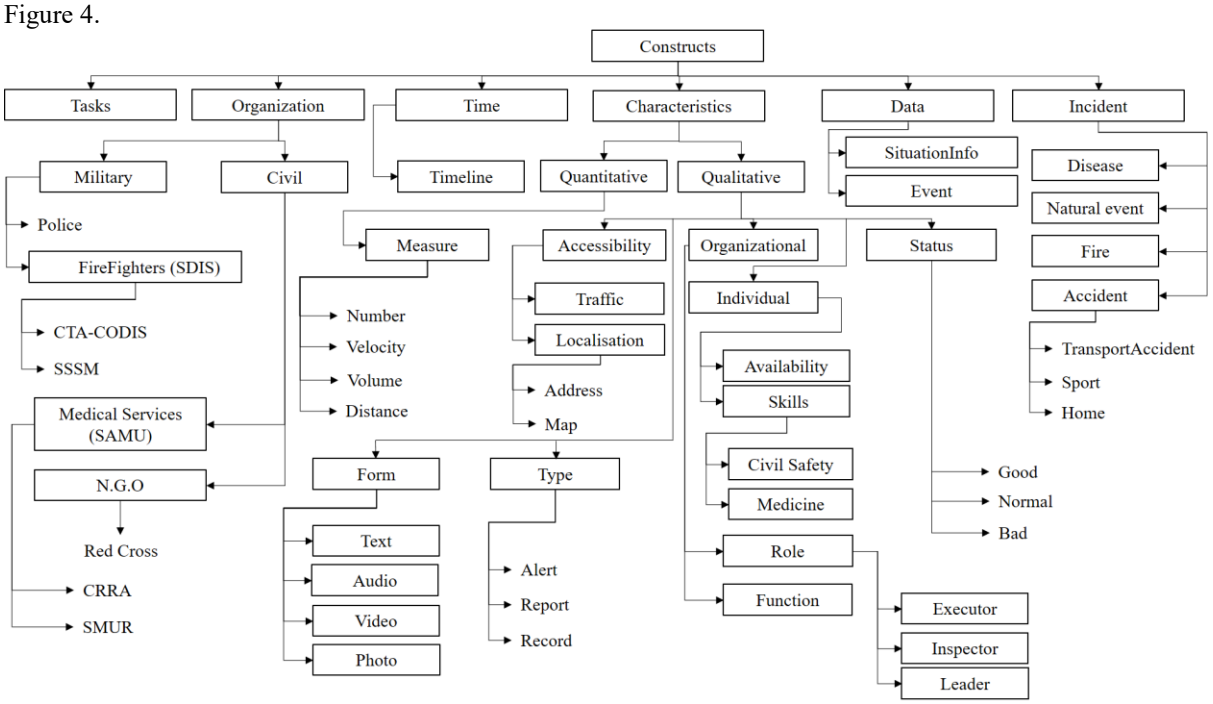


Figure 3. Hierarchy of Constructs

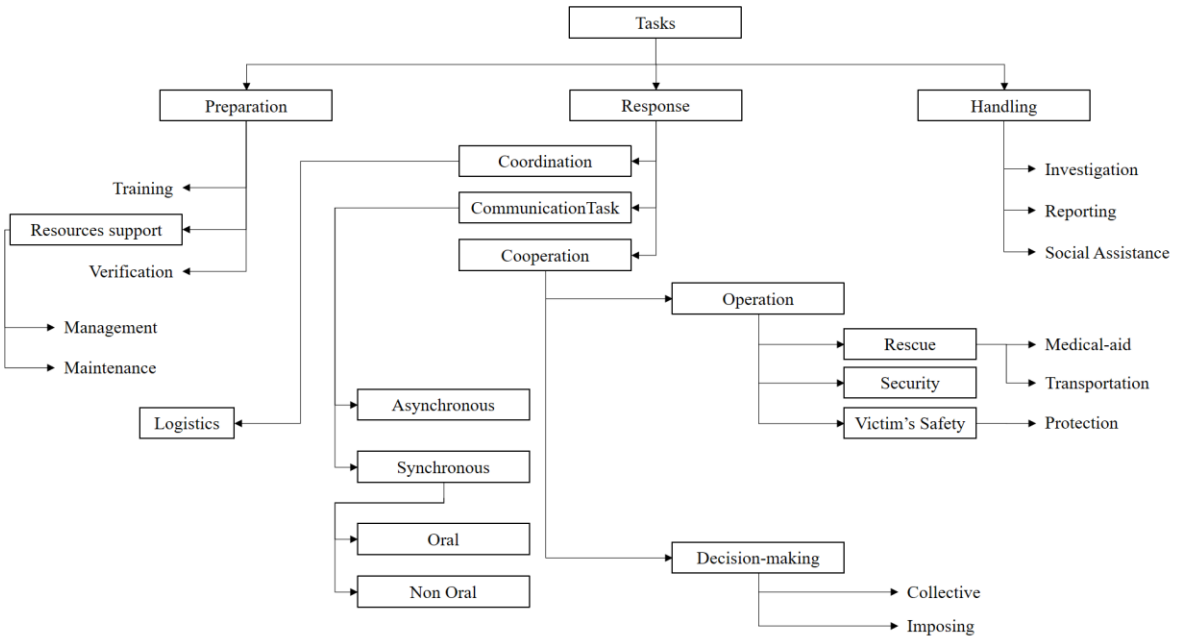


Figure 4. Tasks to be achieved

Finally, we moved to the last step: the Operationalization.

Operationalization

The last step consists in implementing the ontology in a system using a formal representation language. The result is called computational ontology (Bachimont et al., 2002). To do that, we used Protégé 5.2 (https://protege.stanford.edu/products.php#desktop-protege), which enables building OWL-based ontologies (Musen, 2015). The advantage of using Protégé is that it enables building ontologies, defining rules and doing

required inferences. In this step, we defined our concepts and sub-concepts as classes and sub-classes. Figures 5 and 6 show the classes defined under **OBJECTS** and **CONSTRUCTS** respectively.

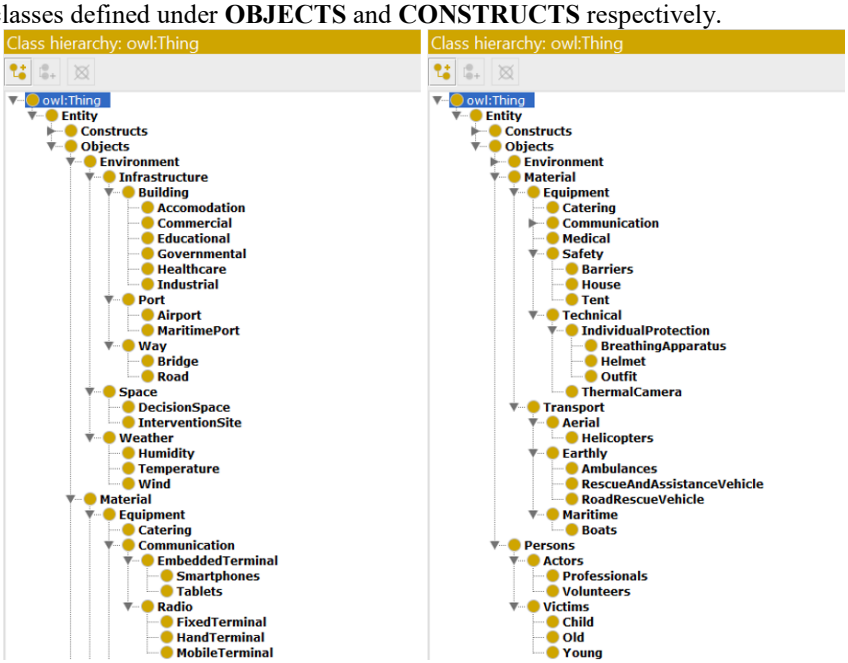


Figure 5. Classes of Objects

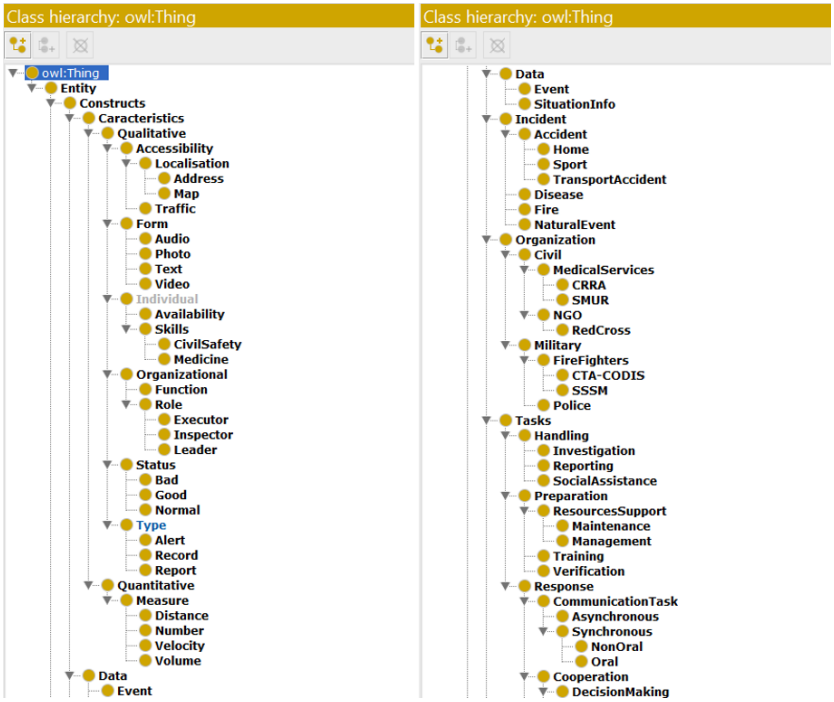


Figure 6. Classes of Constructs

After that, we identified properties of concepts. These properties are the relations between concepts. Figure 7 shows an example of properties defined for the concept Actors.

Figure 7. Example of Properties

After finishing the taxonomy and identifying relations between concepts, we represented the obtained ontology using graphs. These graphs show different concepts and relations between them based on the defined properties. Figure 8 presents an extract of a graph showing different relationships that exist between some concepts of the ontology.

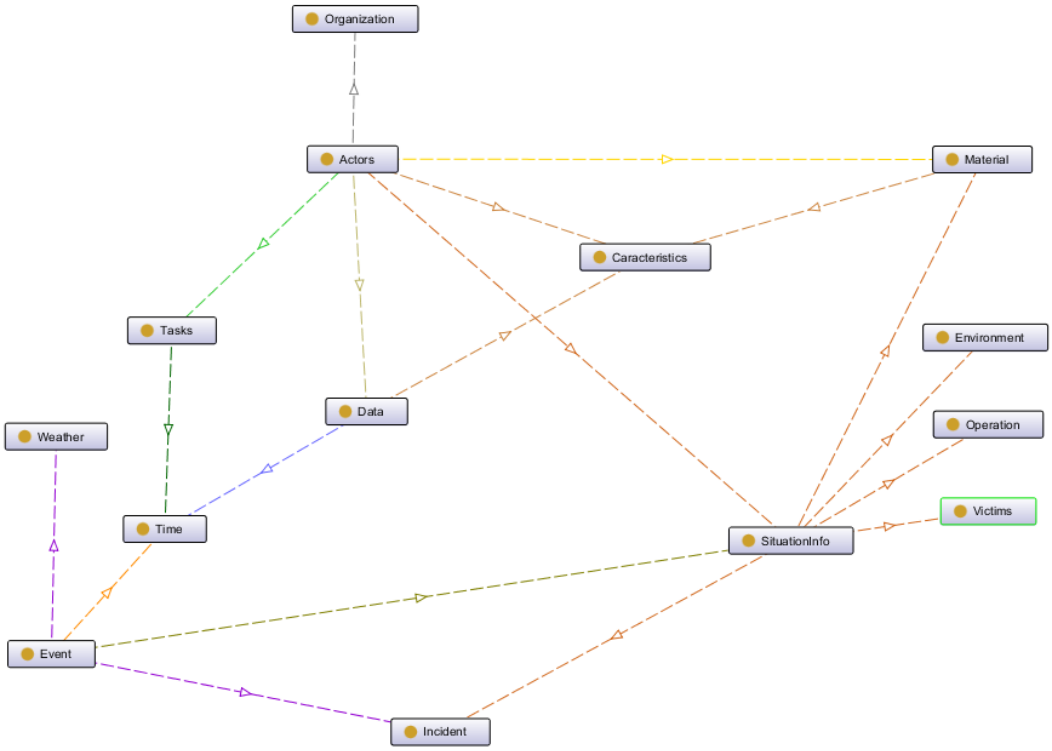


Figure 8. One graph of the implemented Ontology

In this example, we can see that an Actor is a part of an Organization. S/he has Characteristics that can be Individual such as Availability or Organizational such as Function. This actor uses Materials having characteristics too such as the state of the material. S/he transmits Data that is communicated on Time and informs on SituationInfo, which contains information on Operation, Material, Victim, Environment and Incident. An actor does also other Tasks that are scheduled on Time. On a certain Time, an event can occur and affects SituationInfo. This event can be a change in Weather or a sudden Incident.

The work done represents the methodology we adopted and different steps to construct the proposed Ontology. To do that, we identified notions. We gave then definitions and we classified these notions into a taxonomy. After that, we identified properties and relations between concepts and we reorganized our taxonomy. Finally, we implemented this ontology in a computational language OWL using Protégé 5.2 and we represented it using conceptual graphs. As a future step, we look forward to evaluate the developed ontology and submit it to an ontology catalog. The aim of building this ontology is to support situation awareness in rescue operations. It will be used not only for communication and situation's representation but also to help actors to build the relations between elements by using an inference system.

CONCLUSION

Like several dynamic and complex domains, ensuring a high level of situation awareness in rescue operations is difficult. This difficulty is caused by many factors such as multiplicity of actors, dynamicity of situations and difference in situations' perception between a person and another. All these factors and many others can affect actors' performance and decision-making. To respond to this problematic, we constructed an application ontology related to rescue operations in France. It will be used for ensuring common situation representation between actors. This representation helps to unify situations perceptions and understanding between different actors involved in rescue operations and then to enhance situation awareness. It helps also to display important elements in a situation, their evolution and the occurrence of events, which is the basis of situation awareness. To construct the ontology, we adopted a methodology consisting of three steps: Normalization, Formalization and Operationalization. We also studied domain related documentation and several domain existing ontology. After that, we implemented this ontology in OWL language using Protégé 5.2. However, our ontology is not evaluated yet since it is our first study in this aim.

As a future work, we will detail this ontology and instantiate it based on expertise collection and modeling. Thus, we will conduct more interviews with actors from different organizations involved in rescue operations. After that, we will test it in real cases, evaluate it and submit it to an ontology catalog. Finally, we will study the design and implementation of a knowledge based system that will support decision-making and situations understanding in rescue operations environments by exploiting the constructed ontology. This work will include naturally a study about the confidentiality and security of exchanged information.

REFERENCES

Ashish, N., Kalashnikov, D., Mehrotra, S. and Venkatasubramanian, N. (2009) An Event Based Approach to Situational Representation, *arXiv preprint arXiv: 0906.4096*.

Azcona, E. R. (2013) DISASTER Data Interoperability Solution at Stakeholders Emergency Reaction 285069, Available at http://disaster-fp7.eu/sites/default/files/D3.22.pdf (Accessed: November 2018).

Bachimont, B., Isaac, A. and Troncy, R. (2002) Semantic commitment for designing ontologies: a proposal, *International Conference on Knowledge Engineering and Knowledge Management*, pp. 114-121. Springer, Berlin, Heidelberg.

Barros, R., Kislansky, P., Salvador, L., Almeida, R., Breyer, M. and Gasparin, L. (2015) EDXL-RESCUER ontology: Conceptual model for semantic integration, *Proceedings of the 12th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*.

Baumgartner, N., Gottesheim, W., Mitsch, S., Retschitzegger, W. and Schwinger, W. (2010) BeAware!—situation awareness, the ontology-driven way. *Data & Knowledge Engineering*, *69*(11), pp. 1181-1193.

Bergstrand, F. and Landgren, J. (2009) Information sharing using live video in emergency response work, *Proceedings of the 6th International ISCRAM Conference*, pp. 1-5.

Bouaud, J., Bachimont, B., Charlet, J. and Zweigenbaum, P. (1995) Methodological principles for structuring an "ontology", *Proceedings of the IJCAI'95 Workshop on "Basic Ontological Issues in Knowledge Sharing"*, pp. 19-25.

Chehade, S., Matta, N., Pothin, J. B. and Cogranne, R. (2018) Data Interpretation Support in Rescue Operations: Application for French Firefighters, *Proceedings of the 15th ACS/IEEE International Conference on Computer systems and applications (AICCSA)*.

Comité quadripartie associant les représentants des structures de médecine d'urgence et des services d'incendie et de secours, la DDSC et la DHOS. (2008) Common Referential Organization of Personal Relief and Urgent Medical Assistance, Référentiel Commun Organisation du Secours à personne et de l'Aide Médicale Urgente.

Diederichs, O., Paulot, J. M., Mauss, H. and Maymil, V. (2006) Rescue of people, Secours à personne, *Rapport de l'Inspection générale de l'administration IGAS.*

Endsley, M. R. (1995) Toward a Theory of Situation Awareness in Dynamic Systems: Situation awareness. In *Human Factors*, Vol. 37, pp. 32-64. Human Factors and Ergonomics Society

Endsley, M. R. and Robertson, M. M. (1996) Team situation awareness in aviation maintenance, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 40, No. 21, pp. 1077-1081, Sage CA: Los Angeles, CA: SAGE Publications.

Endsley, M. R. (2006) Situation awareness. *Handbook of human factors and ergonomics*, pp. 553-568.

Engelbrecht, A., Borges, M. R. and Vivacqua, A. S. (2011) Digital tabletops for situational awareness in emergency situations, *15th International Conference on Computer Supported Cooperative Work in Design (CSCWD),* pp. 669-676), IEEE.

Gangemi, A., Guarino, N., Masolo, C. and Oltramari, A. (2003) Sweetening WORDNET with DOLCE, *AI Magazine*, vol. 24, no. 3, p. 13.

Gruber, T. R. (1993) A translation approach to portable ontology specifications, *Knowledge Acquisition*, vol. 5, no. 2, pp. 199–220.

Javed, Y., Norris, T. and Johnston, D. (2011) Ontology-based inference to enhance team situation awareness in emergency management, *Proceedings of the 8th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*, pp. 1-9.

Kokar, M. M., Matheus, C. J. and Baclawski, K. (2009) Ontology-based situation awareness, *Information fusion*, *10*(1), pp. 83-98.

Kokar, M. M. and Endsley, M. R. (2012) Situation awareness and cognitive modeling, *IEEE Intelligent Systems*, *27*(3), pp. 91-96.

Konstantopoulos, S., Paliouras, G. and Chatzinotas, S. (2006) SHARE-ODS: An ontology data service for search and rescue operations, *Hellenic Conference on Artificial Intelligence,* pp. 525–528. Springer, Berlin, Heidelberg.

Kulyk, O., van der Veer, G. and van Dijk, B. (2008) Situational awareness support to enhance teamwork in collaborative environments, *Proceedings of the 15th European conference on Cognitive ergonomics: the ergonomics of cool interaction,* pp. 1-5, ACM.

Larochelle, B., Kruijff, G. J. M., Smets, N., Mioch, T. and Groenewegen, P. (2011) Establishing human situation awareness using a multi-modal operator control unit in an urban search & rescue human-robot team, *Proceedings of the 20th IEEE International Symposium on Robot and Human Interactive Communication*, pp. 229-234, IEEE.

Li, X., Liu, G., Ling, A., Zhan, J., An, N., Li, L. and Sha, Y. (2008) Building a practical ontology for emergency response systems, *Proceedings of the International Conference on Computer Science and Software Engineering, CSSE 2008*, vol. 4, pp. 222–225.

Matheus, C. J., Kokar, M. M. and Baclawski, K. (2003) A Core Ontology for Situation Awareness, *Sixth International Conference on Information Fusion*, vol. 1, pp. 545-552.

Matuszek, C., Cabral, J., Witbrock, M. and Deoliveira, J. (2006) An introduction to the syntax and content of Cyc, *AAAI Spring Symposium: Formalizing and Compiling Background Knowledge and Its Applications to Knowledge Representation and Question Answering*, vol. 3864, no. 1447, pp. 44–49.

Mizoguchi, R., Ikeda, M., Seta, K. and Vanwelkenhuysen, J. (1995) Ontology for Modeling the World from Problem Solving Perspectives, *Proceedings of IJCAI95 Workshop on Basic Ontological Issues in Knowledge Sharing*. pp. 1–12.

Musen, M. A. (2015) The Protégé project: A look back and a look forward. *AI Matters. Association of Computing Machinery Specific Interest Group in Artificial Intelligence*, *1*(4). DOI: 10.1145/2557001.25757003.

Nunavath, V., Prinz, A., Comes, T. and Radianti, J. (2016) Representing fire emergency response knowledge through a domain modelling approach (Google Scholar).

Pease, A., Niles, I. and Li, J. (2002) The Suggested Upper Merged Ontology: A Large Ontology for the Semantic Web and its Applications, *Imagine*, vol. 28, pp. 7–10.

Riley, J. M. and Endsley, M. R. (2004) The hunt for situation awareness: Human-robot interaction in search and rescue, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 48, No. 3, pp. 693-697. Sage CA: Los Angeles, CA: SAGE Publications.

Schütte, F., Casado, R. and Rubiera, E. (2013) Solving Interoperability Issues in Cross Border Emergency Operations, *Proceedings of the 10th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*, pp. 238–241.

Smart, P. R., Russell, A., Shadbolt, N. R. and Carr, L. A. (2007) AKTiveSA: A technical demonstrator system for enhanced situation awareness. *The Computer Journal*, *50*(6), pp. 703-716.

Sowa, J. F. (2000) *Knowledge representation: Logical, Philosophical, and Computational Foundations* (Vol. 13). Pacific Grove: Brooks/Cole.

Sowa, J. F. (2008) Conceptual Graphs, *Foundations of Artificial Intelligence*, vol. 3, no. Findler 1979, pp. 213−237.

Studer, R., Benjamins, V. R. and Fensel, D. (1998) Knowledge engineering: Principles and methods, *Data & Knowledge Engineering*, vol. 25, no. 1–2, pp. 161–198.

Villela, K., Breiner, K., Nass, C., Mendonça, M. and Vieira, V. (2014) A smart and reliable crowdsourcing solution for emergency and crisis management, *IDIMT 2014: Networking Societies – Cooperation and Conflict, 22nd Interdisciplinary Information Management Talks*, pp. 213–220.

Velde, L. V., Chatzinots, S., Larson, M., Löffler, J. and Paliouras, G. (2005) Interactive 2D - 3D digital maps for the support of emergency teams during rescue operations, *Intelligent Transportation Society of America - Proceedings of the 12th World Congress on Intelligent Transport Systems,* vol. 3, pp. 1575–1584.

Yu, K., Wang, Q. and Rong, L. (2008) Emergency ontology construction in emergency decision support system, *Proceedings of 2008 IEEE International Conference on Service Operations and Logistics, and Informatics, IEEE/SOLI 2008*, vol. 1, pp. 801–805.

Video Summarization And Video Highlight Selection Tools To Facilitate Fire Incident Management

Florian Vandecasteele
Ghent University - IDLAB
Florian.Vandecasteele@ugent.be

Krishna Kumar
Ghent University-IDLAB
krishnakumar.tc@ugent.be

Kenzo Milleville
Ghent University - IDLAB
Kenzo.Milleville@ugent.be

Steven Verstockt
Ghent University - IDLAB
Steven.Verstockt@ugent.be

ABSTRACT

This paper reports on the added value of combining different types of sensor data and geographic information for fire incident management. A survey was launched within the Belgian fire community to explore the need of added value and the use of new types of sensor data during a fire incident. This evaluation revealed that people are visually-oriented and that video footages and images are of great value to gain insights in a particular problem. However, due to the limited available time (i.e., fast decisions need to be taken) and the large amount of cameras it is not feasible to analyze all video footages sequentially. To solve this problem we propose a video summarization mechanism and a video highlight selection tool based on the automatic generated image and video tags.

Keywords: machine learning, video data, filtering, crisis management, user-evaluation

1 INTRODUCTION

During the first minutes of an intervention, the incident officer needs to take fast and appropriate decisions with very limited information. However, the scene layout, the structure of the building, the fire dimensions and position, the hazardous materials present, and the status and the position of victims, are factors that affect the initial strategy and tactics.

Currently, there are two main communication tools for fire incident management: a broadcast channel for voice communication and a second textual channel for status updating. However, from a psychological perspective it is proven that our brain is better at processing visuals than text [1]. Our brain can process an image 60 000 times faster than a piece of text. On average, when a person sees a particular image for the first time, it takes 113 milliseconds to process the information. In that sense it is advisable to focus on the development of image related tools to facilitate the incident officers instead of improving the existing auditive or textual communication tools that have problems with reliability (e.g., connection-loss in concrete buildings) and interoperability.

To generate the needed visual information we can exploit the increased performance and quality of fixed security cameras and handheld devices such as smartphones and tablets. It is important, however, that the video footage is captured in the most appropriate way for visualization to a fire incident manager. Furthermore, the sensor input of the fixed and handheld cameras can be streamed to the incident commander to have an overview of the incident scene. However, it is not possible for a person to analyze all the video streams in a sequential manner due to the cognitive disability. There is a need for a video summarization mechanism that filters out the redundant and unnecessary frames, while preserving the distinctive frames.

Besides the visual camera information there are other sensor types (e.g., temperature indications, CO levels) with valuable information for the incident commander. Visualizing too many sensors will lead to enacted sensemaking where an individual will select unconsciously some parts of the data to make their decision. Especially in critical or stress situations this can lead to overshooting or undershooting of the situation. To solve these issues the firefighting community should get aware of the opportunities of web dashboards to quickly and easily create reports and data visualizations [2]. The core idea of dynamic dashboards is to efficiently display data in such a way that it can enhance user insight into the data. An example is the fire probability calculation and visualization for residential regions by Netage. Similarly, the Moses project explored a dashboard system for seamless localization, employability and health status monitoring (e.g., heart rate, air consumption) of firefighters.

The remainder of this paper is organized as follows. Section 2 presents the specific information needs of first responders. Furthermore in Section 2 the data insights from the questionnaire are discussed more thoroughly. Section 3 goes more in detail into the video summarization process. Subsequently, Section 4 proposes the possibilities for video and frame retrieval. Next, Section 5 discusses the results of our proposed methodology and Finally Section 6 gives some conclusions and suggestions for future work.

2 FIRST RESPONDERS INFORMATION NEEDS

2.1 Visible and cognitive disability

Biologically, human beings have psychological restrictions in terms of observing and processing information. Furthermore, an individual can only process a limited amount of simultaneous stimuli. Ungerer et al. [3] stated that a person can only process a fraction of the information in a conscious way. According to his theory, each second 3 up to 5 visual and 3 auditive or tactile inputs can be processed simultaneously. Schaub et al. [4] on the other hand denoted that a human is only capable of processing 7 concurrent signals.

The head of operations and firefighters in general have to work in difficult, often unknown contexts, where there is an increased stress level. Subsequently, due to the increased level of stress there is a higher chance of reduced cognitive ability. Despite the dynamic and difficult character, decisions need to be made without detailed investigation or analysis. In general the fire scene is a complex situation due to the following factors:

- A comprehensive list of 'unknown' variables (e.g., number of people present, evacuation necessity, fire behavior, fire expansion and building contents);
- Variables that affect each other (e.g., ventilation openings will change the fire growth);
- Variables that change in time and space without being transparent or predictable.

Due to the risk of reduced cognitive ability and the psychological restrictions there is a need for a smart, adaptive visualization application. The time first-responders spend on gathering static and volatile situational information from affected people as well as from responsible persons at the emergency site can be reduced if they have access to the needed information. The following subsections will discuss the related work for fire incident visualization and the subjective criteria for data importance rating.

2.2 Related work

Nunavath et al. identified the information needs for first responders from a literature review, fire drills and interviews. Prioritizing of information items is needed for different stages of building fire emergency response operations and to ensure a maximum of 7 concurrent decision signals. The most commonly mentioned information item in the work of Nunavath et al. is the building related information, which includes important information about the building layout plans, hazardous material location, resources location, floors, and rooms. Furthermore, the other most commonly mentioned information item was fire related information such as color, location and condition of the fire which can be derived with the techniques of Beji et al. [5] and Vandecasteele et al. [6]. Subsequently, Li et al. [7] investigated the information sources used in current practice (year 2013) and those desired to be used in the future. Furthermore, Li et al. considered the information items needed by first responders and the availability of technological solutions to obtain them in the United Stated. Furthermore, Li et al. mention that there are three timings where data should be delivered: before arrival, when arriving at the emergency scene and during the attack and the mitigation. In an automatic framework these three states should also be considered and evaluated. Hamins et al. [7] created the smart-firefighting roadmap and although, the roadmap gives some directions for further research, currently only limited implementations are available. This paper proposes some technological building blocks to start with 'smart-firefighting'. Finally, emergency

responders have different roles to perform, different tasks to handle, and different modes to communicate, which lead to an insufficient view of the complete emergency situation at the emergency site. In that respect Nunavath et al. [8] presented a conceptual domain model. Their model consists of four components: event component, actor component, objective component and building component. Each component contains several information resources and all components capture the complete building fire emergency response. However, as stated before it is not feasible to process all components sequentially and filtering and summarization mechanisms will be necessary.

2.3 Subjective criteria and discussion

Within the Belgian fire community, a survey was launched to explore the necessity and the use of new types of sensor data during a fire incident. This survey can be seen as an updated version of to the work of Li et al. The questionnaire was sent to all Flemish firefighting communities and input was asked from all hierarchical levels (i.e., strategic, tactical and operational). Furthermore, we targeted a balance in the ratio of volunteer and professional firefighters that filled in the inquiry. 21 different questions were asked and the first question was: ”What kind of data should be available during an incident?”. From the survey results it was remarked that the thermal imaging device (95,9% of respondents) is the most informative device used by firefighters, followed by the explosion warning device (65,8%) and the visual camera (65,7%). In the questionnaire it was pointed out that the more information available during an incident, the higher the fire crew score their situational awareness. However, as stated earlier in this section, there is a maximum of 7 simultaneous inputs that can be used. The most important features are the location of the fire source, the amount and the position of the victims and firefighters, and the structure and lay-out of the building.

Subsequently, in the questionnaire, some questions were related to the priority of the data. The camera footages, the thermal camera footages and the surrounding temperature were pointed out as prior. It is important to remark that this should be re-evaluated within a couple of years as most of the other sensor and data values are currently not available during an intervention and the decision makers are not trained to use certain variables. Furthermore, the questionnaires indicated that they allow a maximum processing time (i.e., delay to receive the first information) for the video streaming of 1 minute.

3 VIDEO SUMMARIZATION

As indicated in the questionnaire, decision makers want to have access to visual and thermal video streams. As it is not possible to analyze the complete history of a CCTV camera and it is not possible to investigate several cameras simultaneously, there is a need for video summarization. Video summarization can be classified into two types, namely static video summarization and dynamic video summarization. Static summarization results in a set of keyframes that best conveys the overall idea of the video. In most cases, keyframes are representative frames that could identify either the beginning or end of a scene transition in a video sequence. The number of resulting keyframes can vary as per the setting. Contrary, dynamic summarization collects small chosen fragments of the original video and arranges these fragments to obtain a new version of the video (i.e., logical story units).

Depending on the use case (e.g., fire incident, hazard materials incident) and the commanders function (e.g., evaluating the evacuation, investigating the structural damage or making strategic decisions for the intervention crews) different static or dynamic fragments will be indicated as important. Furthermore, personalized interaction will be necessary to learn the visualization needs based on the incident type, the operational function and the geographical location. The main focus of the following sections is on the static summary generation as it is not feasible to analyze several logical story units sequentially in a fast manner.

A schematic overview of our proposed indexing strategy is given in Figure 1. First the different video sensors are captured. Secondly, the video summarization selects a set of representative keyframes. Thirdly, for each keyframe the scene content understanding is performed and indexed. Finally, the user can visualize and query the set of keyframes on a semantic and visual level.

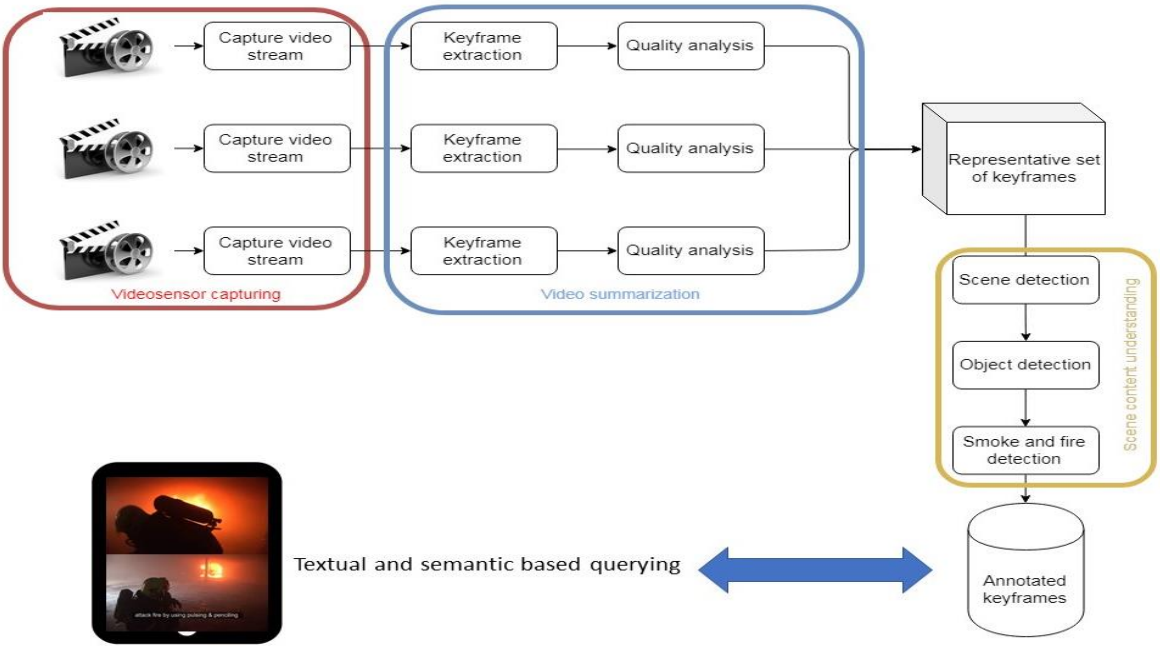


Figure 1. Schematic overview of the video capturing, summarization and content understanding process.

In order to visualize the relevant keyframes in a dashboard system and to decrease the computational cost of subsequent video processing tasks it is important to reduce the amount of video data by filtering out redundant and unnecessary frames, while preserving only those frames, distinctive and essential, to capture the entire video content. Furthermore, presenting the end-user with a limited list of representative keyframes instead of dynamic video fragments, improves their exploration, understanding and search process. Therefore the main focus of the following sections is on the static summary generation. The automated summarization of video content into representative keyframes, however, is a challenging problem due to the rapid change in lightning, viewpoint, and scene. In order to cope with these issues, we present a novel solution to extract, cluster, and filter meaningful keyframes. This summarization process consists of three major steps:

- The video summarization converts the video into a set of representative keyframes. All the keyframes represent one single video shot. These shots are detected using a grid-based histogram detection method and within each shot no-reference keyframe quality analysis is used to select the best frame within the shot as proposed by Vandecasteele et al. [9].

- The number of keyframes is reduced by clustering visually similar frames, while preserving as much as possible of the entire content.

- A limited set of representative keyframes is given to the object and scene retrieval algorithms to generate meaningful tags. This is out-of-scope of this paper, but more details can be found in the work of Vandecasteele et al. [10].

Much research has been done in the area of video summarization (i.e., keyframe retrieval). Ajmal et al. [11] give an overview of the different techniques and classification methods that are commonly discussed in literature, i.e., feature classification [12], clustering [13], shot selection [14] and trajectory analysis [15]. In the following subsection the grid-based histogram shot detection approach is proposed.

3.1 Shot detection

Compared to the state-of-the-art temporal shot segmentation algorithms [16], the proposed local histogram analysis on a 5-by-5 grid copes better with fast camera movements, zoom gestures, and similar scene discrimination (i.e., problems that arise in handheld video analysis. The proposed algorithm consists of 4 major steps:

- A conversion to gray scale frames;
- A rasterization (splitting) of each frame in a 5-by-5 grid and a calculation of the histogram for each cell in the grid;
- A correlation based temporal analysis of each histogram;
- A calculation of the amount of changed cells. If this is larger than an experimentally defined threshold the transition is seen as a shot.

The histogram based shot detection has an outstanding performance on detecting hard and gradual shots, which makes it suitable to process all kinds of video content (i.e., handheld and CCTV data streams). The only limitation is that it does not handle similar scenes very well, but this is solved in Section 3.3. In order to cope with gradual shots, like blends and fades, we also count the amount of frames that have been passed since the last detected transition. If that amount is too low and a new transition is found, we consider it to be the same transition. This way we successfully manage to detect both gradual- and abrupt scene transitions.

3.2 No-reference keyframe quality analysis

Currently, multiple image quality metrics are available [17]. However, most of them need a reference image or they are not suitable for real-time quality measurement. In our methodology, based on the detected shot boundaries, the frame with the highest quality within each shot is chosen as a representative keyframe. The quality is estimated using a weighted set of three no-reference quality metrics that are suitable for real-time images as proposed by Vandecasteele et al. [9]. The proposed no-reference exposure, contrast and sharpness metrics are evaluated on a variety of video footages.

3.3 Similarity clustering

In general, a video scene consists of many shots that are visually similar (i.e., taken in the same scene setting). On the one hand, removing these redundant and unnecessary frames improves the summarization visualization on a small screen or on a tablet. On the other hand, clustering the similar keyframes will decrease the time for tag generation i.e., an automatic annotation can be performed on all object representations within the same cluster.

The clustering process is done in three steps. First, we perform a global feature extraction with CNN based learned features as proposed by Zagoruyko et al. [18]. Subsequently, we do a feature reduction by using the principal component analysis (PCA) technique. Finally, we use k-means clustering with the L2-distance of the reduced features of the keyframe. Furthermore, it is important to remark that if the amount of clusters is too high, redundant keyframes will appear. On the other hand, if the amount of clusters is too low, outliers (i.e., very unique keyframes or single scene shots) will not be shown.

4 VIDEO AND FRAME RETRIEVAL

The set of keyframes (from different camera viewpoints and camera sources) could still be too versatile and to improve the fast exploration two additional mechanisms are proposed: (I) an automated importance scoring based on the scene content and (II) a semantic web-based querying tool as proposed by Verstockt et al. [19]. Furthermore, the tags that are generated from the scene understanding process are used as input for both mechanisms. Figure 2 gives a schematic overview of the scene content understanding framework.

4.1 Automated scene content understanding

4.1.1 Scene type detection

Over the last decade, several literature studies have already shown impressive results regarding the classification of indoor and outdoor scenes [20], and more recent studies have added the ability to predict more detailed attributes, such as the scene type, e.g., kitchen, living room, or bedroom. Zhou et al. [21] constructed a new scene-centric database named Places, containing over 7 million labeled pictures of scenes distributed over 365 classes. Currently, the state-of-the-art systems for scene classification are based on CNNs, mostly trained using a transfer learning approach on the ImageNet models [21]. For the scene classification task the current highest top-5 accuracies achieved on this Places dataset are 85,08 percent with the RESNET architecture [22].

4.1.2 Visual and thermal object localization

Despite the broad application of handheld thermal imaging cameras in firefighting, its usage is mostly limited to subjective interpretation by the person carrying the device. As remedies to overcome this limitation, object localization and classification mechanisms [23, 24] could assist the fireground understanding and help with the automated localization, characterization and spatial-temporal (spreading) analysis of the fire. An automated understanding of thermal images can transform the conventional knowledge-based firefighting into sensor-driven based firefighting. In this paper, transfer learning is applied to multi-labeling convolution neural network architectures for object localization and recognition in monocular visual, infrared images. More details are given in the work of Vandecasteele et al. [25].

4.1.3 Room configuration estimation optimization

Intuitively, individual predictions of objects and relationships can benefit from their surrounding context (i.e., the probability to predict a bed, given that he room is a sleeping room is much higher compared to a kitchen). In our work we optimized the scene classification results by exploiting the object detections. First we learned the object co-occurrence from the ObjectNet3D dataset. Some preprocessing was necessary to remove the objects that appear only once in the dataset. Furthermore the classes *'floor', 'ceiling'* and *'wall'* were removed from the object dataset as they are not descriptive for a specific room type. The object co-occurrence will assist the thermal object detection by indicating the objects that are related to the detected classes. For example if a chair is detected, there is a 60 percent chance that there will be a table in the same scene. This can then be incorporated in the fire load calculation.

4.1.4 Fire and smoke characteristics

Video based fire detection and analysis with cameras has been discussed several times in literature over the past years [26]. Different features, such as color, pixel disorder, wavelet analysis are combined with simple linear classifiers or with more advanced deep learning mechanisms [27]. However, the focus in literature was mainly on the detection, the propagation of the smoke, the height of the smoke layer or the visibility for example, were investigated less. Within our framework, the smoke and fire probability are calculated with the techniques of Frizzi et al. [27]. Finally, the visibility on each frame is calculated with the techniques of Vandecasteele et al. [6], the visibility is thereby scored between High-visibility (5) up to No-visibility (0).

4.2 Importance scoring

The content of the scene is important because it includes useful information that attracts the viewer (e.g., the decision maker). Rationally, the objects and locations that are shown for a longer period of time in the handheld video have a higher chance to be of importance. It is important to remark that further user-driven evaluations will be necessary to prove this statement. Furthermore, since there are tags pertaining to all the frames it is necessary to alter them and to preserve only the most informative words that define the main semantic components. This is done as follows. First the tags are preprocessed by tokenization and part-of-speech tagging. After the extraction, the saliency score for each subset s is calculated according to the words they contain. In combination with the similarity score (e.g., two visualized keyframes should be sufficiently dissimilar), the importance scoring is used to automatically present a couple of keyframes to the decision makers. Still, user evaluations and annotations could help improve and validate the automated video selecting. Besides the automated selecting of the keyframes, we propose a semantic querying system that allows to manually find the most related frames.

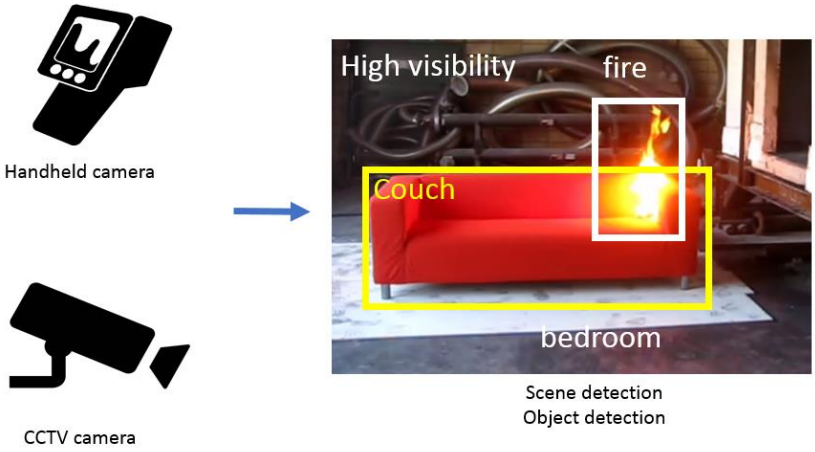


Figure 2. Automated scene content understanding from video footages (e.g., handheld and CCTV cameras).

4.3 Semantic based querying

The web-based tool that could be used to explore the enriched (i.e., the annotated) keyframes is a metadata filtering and clustering service. The querying mechanism can be activated in three different ways:

- A textual input where the user can type the tag that he wants. In case the input is not in the list of predefined tags, the tag with the closest path distance (i.e., the highest similarity) according to Wordnet [28] is selected. However, other semantic distance metrics can easily be integrated.

- A drop-down list with predefined tags (e.g., places, fire-related topics, evacuation keywords), where the user can select the necessary tags (e.g., show all the keyframes annotated with kitchen and fire).

- An interactive, hierarchical ontology visualization where the user can select and easily search for the best matching tags. Furthermore, if a tag on a higher semantic level in the hierarchy is selected, all the underlaying and related tags are selected (e.g., if the tag opening is selected, the tags door and window are likewise selected).

> *An ontology is a representation, formal naming, and definition of the categories, properties, and the relations between the concepts, data, and entities over one or more domains.*

The semantic similarity is currently calculated based on the ontology of Zhang et al. [29], but new ontologies can easily be integrated. Zhang et al. proposed a street scene ontology for qualitative understanding of outdoor scenes. This is valuable for large multi-disciplinary fire incidents as it contains building elements (e.g., floor, window, wall, column), but also construction, land and terrain elements. Some alternative ontologies that can be used are, for example, the work of Kadar et al. [30] who created a database of 100 scene categories (e.g., classroom, bathroom, bedroom, alley) derived from human vision. This ontology could be valuable in indoor firefighting scenarios. Jaoa et al. [31] created an ontology on how scene situations progress in time. The FIRE ontology was created in order to represent the set of concepts about the fire occurring in natural vegetation, its characteristics, causes and effects. Similar concepts and effects are found in indoor fire situations. Poveda et al. [32] created an ontology for designing and validating emergency plans and the sensor, users and furniture connections are highly valuable for our framework.

5 RESULTS AND DISCUSSION

Murugan et al. [33] proposed various methods for video summarization for surveillance applications still latter discussion was given on the exportability of the video footages. Within this Section a subjective evaluation is performed on our proposed mechanisms. Video footages from multidisciplinary incidents are taken as input for our evaluation. Figure 3 gives a schematic overview. First the video footages are selected (currently, this is a manual task, but the integration of online IP-cameras should be easily possible). Secondly, the keyframe extraction, similarity removal and no-reference analysis is used to select the most representative keyframes. Thirdly, the semantic tag understanding process is elaborated to automatically generate tags for each frame. Finally, the exploration and selection tools are used to get a fast overview of the current state of the incident and the actions.

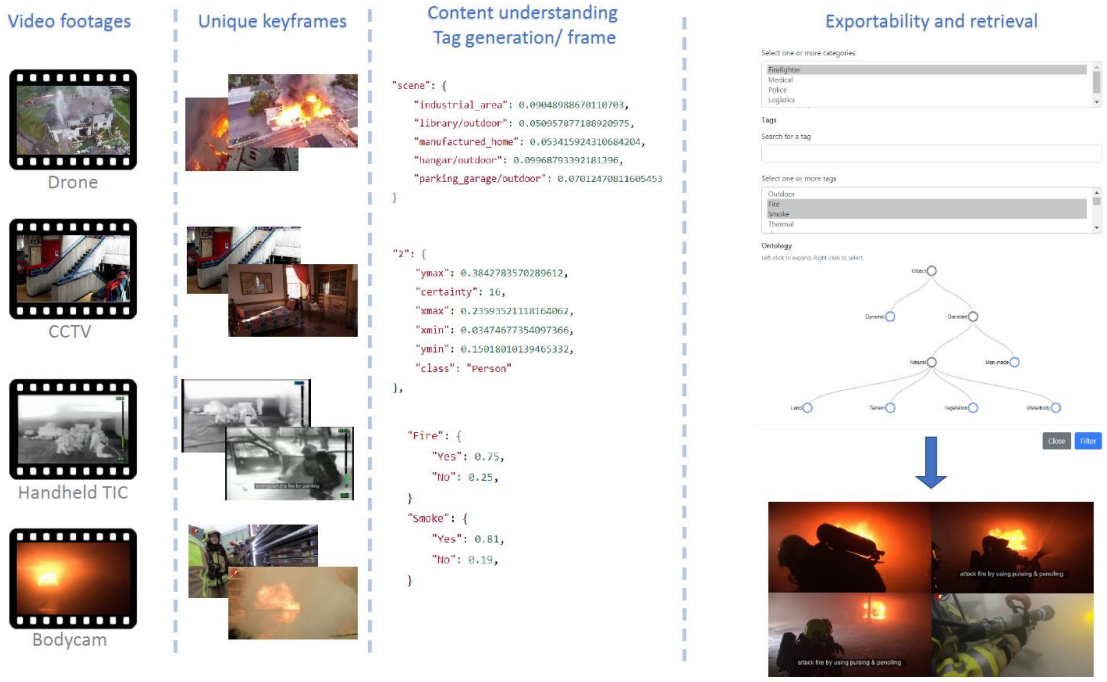


Figure 3. Schematic overview of the video footage analysis framework, first the footage linking, secondly the keyframe generation, thirdly the content understanding tool and finally the frame retrieval tool.

Some improvements for the tag generation are the classification into categories, for example an additional classifier into medical, police, fire service. Furthermore, it is valuable to add the source of the video footage as a tag (e.g., handheld camera first crew, TIC second crew, drone footage). Finally, as indicated earlier in this section, the video summarization and retrieval building blocks require further user-driven evaluations. Still the feasibility of the proposed building blocks is shown in this paper. Real-fire experiments that are recorded from different point-of-views and with different resources are highly valuable for further evaluation and improvement.

6 CONCLUSION

This paper presented the user-needs and data restrictions specific for fire incident management. The insights were gained through the analysis of a questionnaire launched in the firefighting community of Belgium. This evaluation revealed that people are visually-oriented and that video footages are great to gain insights into a problem. Still, people can only process 7 image inputs simultaneous and for that reason, the video summarization framework, consisting of shot detection, frame quality and similarity analysis was proposed. Subsequently, in order to facilitate the video search process, the video and frame retrieval mechanism was clarified and semantic tag based querying on an existing ontology map was initiated. Future work will focus on video analytics to perform person recognition, crowd analysis(e.g., detecting the amount of people and their behavior) and anomaly detection on global scale. Maybe in the future, even before a fire incident will occur the video analysis will notify suspicious behavior and faster interventions could reduce the economic and material damage. Subsequently, more user-evaluations and usability testing will be necessary to make a complete product out of our proposed framework. Therefore the next step is to organize an usability evaluation using the System Usability Scale (SUS)[34]. Finally a closed field test (limited set of users) and a open field test will give insights in the required development steps.

7 ACKNOWLEDGMENTS

The research activities as described in this paper were funded by Ghent University through GOA project BOF16/GOA/004.

8 REFERENCES

[1] M.M. Chun, Contextual cueing of visual attention, Trends in cognitive sciences, 4 (2000) 170-178.
[2] O. Janssens, Data-driven performance monitoring, fault detection and dynamic dashboards for offshore wind farms, in, Ghent University, 2017.
[3] F. Ungerer, H.-J. Schmid, An introduction to cognitive linguistics, Routledge, 2013.
[4] D. Dörner, H. Schaub, Errors in planning and decision-making and the nature of human information processing, Applied psychology, 43 (1994) 433-453.
[5] T. Beji, S. Verstockt, R. Van de Walle, B. Merci, On the use of real-time video to forecast fire growth in enclosures, Fire Technology, 50 (2014) 1021-1040.
[6] F. Vandecasteele, B. Merci, S. Verstockt, Reasoning on multi-sensor geographic smoke spread data for fire development and risk analysis, Fire Safety Journal, 86 (2016) 65-74.
[7] N. Li, Z. Yang, A. Ghahramani, B. Becerik-Gerber, L. Soibelman, Situational awareness for supporting building fire emergency response: Information needs, information sources, and implementation requirements, Fire safety journal, 63 (2014) 17-28.
[8] V. Nunavath, A. Prinz, T. Comes, J. Radianti, Representing fire emergency response knowledge through a domain modelling approach, (2016).
[9] F. Vandecasteele, K. Vandenbroucke, D. Schuurman, S. Verstockt, Spott: On-the-Spot e-Commerce for Television Using Deep Learning-Based Video Analysis Techniques, ACM Trans. Multimedia Comput. Commun. Appl., 13 (2017) 1-16.
[10] F. Vandecasteele, B. Merci, S. Verstockt, Fireground location understanding by semantic linking of visual objects and building information models, Fire Safety Journal, 91 (2017) 1026-1034.
[11] M. Ajmal, M.H. Ashraf, M. Shakir, Y. Abbas, F.A. Shah, Video summarization: techniques and classification, in: International Conference on Computer Vision and Graphics, Springer, 2012, pp. 1-13.
[12] F. Wang, C.-W. Ngo, Summarizing rushes videos by motion, object, and event understanding, IEEE Transactions on Multimedia, 14 (2012) 76-87.
[13] L. dos Santos Belo, C.A. Caetano Jr, Z.K.G. do Patrocínio Jr, S.J.F. Guimarães, Summarizing video sequence using a graph-based hierarchical approach, Neurocomputing, 173 (2016) 1001-1016.
[14] L. Baraldi, C. Grana, R. Cucchiara, Shot and scene detection via hierarchical clustering for re-using broadcast video, in: International Conference on Computer Analysis of Images and Patterns, Springer, 2015, pp. 801-811.
[15] X. Qiu, S. Jiang, H. Liu, Q. Huang, L. Cao, Spatial-temporal attention analysis for home video, in: 2008 IEEE International Conference on Multimedia and Expo (ICME), IEEE, 2008, pp. 1517-1520.
[16] M.R. Mishra, S. Singhai, M. Sharma, A Comparative based study of Different Video-Shot Boundary Detection algorithms, International Journal of Advanced Research in Computer Engineering & Technology (IJARCET), 2 (2013) pp: 282-289.
[17] K. Joy, E.G. Sarma, RECENT DEVELOPMENTS IN IMAGE QUALITY ASSESSMENT ALGORITHMS: A REVIEW, Journal of Theoretical & Applied Information Technology, 65 (2014).

[18] S. Zagoruyko, N. Komodakis, Learning to compare image patches via convolutional neural networks, in: Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2015, pp. 4353-4361.
[19] S. Verstockt, S. Nop, F. Vandecasteele, T. Baert, N. Van de Weghe, H. Paulussen, E. Rizza, M. Roeges, UGESCO-A Hybrid Platform for Geo-Temporal Enrichment of Digital Photo Collections Based on Computational and Crowdsourced Metadata Generation, in: Euro-Mediterranean Conference, Springer, 2018, pp. 113-124.
[20] J. Luo, A. Savakis, Indoor vs outdoor classification of consumer photographs using low-level and semantic features, in: Image Processing, 2001. Proceedings. 2001 International Conference on, IEEE, 2001, pp. 745-748.
[21] B. Zhou, A. Lapedriza, J. Xiao, A. Torralba, A. Oliva, Learning deep features for scene recognition using places database, in: Advances in neural information processing systems, 2014, pp. 487-495.
[22] K. He, X. Zhang, S. Ren, J. Sun, Deep residual learning for image recognition, in: Proceedings of the IEEE conference on computer vision and pattern recognition, 2016, pp. 770-778.
[23] R. Girshick, Fast r-cnn, in: Proceedings of the IEEE international conference on computer vision, 2015, pp. 1440-1448.
[24] W. Liu, D. Anguelov, D. Erhan, C. Szegedy, S. Reed, C.-Y. Fu, A.C. Berg, Ssd: Single shot multibox detector, in: European conference on computer vision, Springer, 2016, pp. 21-37.
[25] F. Vandecasteele, B. Merci, A. Jalalvand, S. Verstockt, Object localization in handheld thermal images for fireground understanding, in: Thermosense: Thermal Infrared Applications XXXIX, International Society for Optics and Photonics, 2017, pp. 1021405.
[26] A.E. Çetin, K. Dimitropoulos, B. Gouverneur, N. Grammalidis, O. Günay, Y.H. Habiboğlu, B.U. Töreyin, S. Verstockt, Video fire detection–review, Digital Signal Processing, 23 (2013) 1827-1843.
[27] S. Frizzi, R. Kaabi, M. Bouchouicha, J.-M. Ginoux, E. Moreau, F. Fnaiech, Convolutional neural network for video fire and smoke detection, in: Industrial Electronics Society, IECON 2016-42nd Annual Conference of the IEEE, IEEE, 2016, pp. 877-882.
[28] T. Pedersen, S. Patwardhan, J. Michelizzi, WordNet:: Similarity: measuring the relatedness of concepts, in: Demonstration papers at HLT-NAACL 2004, Association for Computational Linguistics, 2004, pp. 38-41.
[29] F. Zhang, D. Zhang, Y. Liu, H. Lin, Representing place locales using scene elements, Computers, Environment and Urban Systems, (2018).
[30] I. Kadar, O. Ben-Shahar, SceneNet: A perceptual ontology for scene understanding, in: European Conference on Computer Vision, Springer, 2014, pp. 385-400.
[31] J.P.A. Almeida, P.D. Costa, G. Guizzardi, Towards an Ontology of Scenes and Situations, in: 2018 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA), IEEE, 2018, pp. 29-35.
[32] G. Poveda, E. Serrano, M. Garijo, Designing emergency management services by ontology driven social simulation, IT CoNvergence PRActice, 3 (2015) 17-32.
[33] A.S. Murugan, K.S. Devi, A. Sivaranjani, P. Srinivasan, A study on various methods used for video summarization and moving object detection for video surveillance applications, Multimedia Tools and Applications, (2018) 1-18.
[34] J. Brooke, SUS-A quick and dirty usability scale, Usability evaluation in industry, 189 (1996) 4-7.

Casualty Information Extraction and Analysis from News

Basanta Chaulagain
Pulchowk campus, Institute of Engineering, Tribhuvan University
071bct510@pcampus.edu.np

Aman Shakya
Pulchowk campus, Institute of Engineering, Tribhuvan University
aman.shakya@ioe.edu.np

Bhuwan Bhatt
Pulchowk campus, Institute of Engineering, Tribhuvan University
071bct511@pcampus.edu.np

Dip Kiran Pradhan Newar
Pulchowk campus, Institute of Engineering, Tribhuvan University
071bct516dip@pcampus.edu.np

Sanjeeb Prasad Panday
Pulchowk campus, Institute of Engineering, Tribhuvan University
sanjeeb@ioe.edu.np

Rom Kant Pandey
Sanothimi Campus, Tribhuvan University
romkant@gmail.com

ABSTRACT

During unforeseen situations of crisis such as disasters and accidents we usually have to rely on local news reports for the latest updates on casualties. The information in such feeds is in unstructured text format, however, structured data is required for analysis and visualization. This paper presents a system for automatic extraction and visualization of casualty information from news articles. A prototype online system has been implemented and tested with local news feed of road accidents. The system extracts information regarding number of deaths, injuries, date, location, and vehicles involved using techniques like Named Entity Recognition, Semantic Role Labeling and Regular expressions. The entities were manually annotated and compared with the results obtained from the system. Initial results are promising with good accuracy overall. Moreover, the system maintains an online database of casualties and provides information visualization and filtering interfaces for analysis.

Keywords

Casualty, information extraction, news articles, casualty data visualization

INTRODUCTION

This paper proposes a system to extract casualty related information from news reports of any incident. The incident may be any situation of crisis, disaster, accident or attack that involves casualties - deaths and injuries. In particular, news of road accidents has been used for experimentation in this work.

For the past two decades, online news has been one of the most reliable and real-time source of information. This information when transformed into organized knowledge can have great significance. Road accidents are one of the leading cause of casualties in Nepal. A total of 95,902 crashes, 100,499 injuries and 14,512 deaths were recorded by traffic police over the period of 2001-2013 (Karkee and Lee 2001-2013). The dataset[1] maintained by the Traffic Police provides statistics of a number of accidents, fatality, serious accidents and

[1] Traffic Police Annual Accident Description, https://traffic.nepalpolice.gov.np/index.php/news/traffic-activities/425-annually- accidental-descriptions

normal accidents every fiscal year.

The existing Accident Database System maintained by the Traffic Police suffers from many deficiencies like under-reporting, inconsistencies, inadequate resources and, time-consuming data collection. Moreover, though government records regarding accidents are the most reliable source, the information is not publicly available in many countries, including Nepal (Bhandari et al. 2017). In situations of crisis, such as road accidents, immediate information is mostly reported by local news agencies only. Hence, local news feeds have been chosen for casualty information extraction in this work. Moreover, the extracted information is collected in a database and made available to the public via an online system with analysis and visualization interfaces.

Relevant entities describing the incident such as death and injury, the location of the incident, vehicle involved in the incident, types of vehicles involved, date and day of occurrence are extracted from news feeds. The extracted casualty information is presented in graphical form for analysis based on location, vehicle types and incident dates. The casualty information extraction system works based on Named Entity Recognition, Semantic Role Labeling and Regular expressions.

In the following 'Related works' section, other approaches in literature are discussed and compared. In the 'Methodology' section, the architecture of the system is presented along with proposed methods to extract casualty information. In the 'Results and Analysis' section, some experimental results are presented along with system snapshots and analysis of the results along with limitations of the system. Finally, the paper is concluded along with a discussion of ongoing and future enhancements.

RELATED WORKS

There are a number of online platforms that apply information extraction techniques in different domains e.g. the Europe Media Monitor (EMM) NewsExplorer and the Thomson Reuters Open Calais. The EMM NewsExplorer[2] automatically gathers news articles from around Europe and separates them into clusters of related articles; identifies names of people, places and organizations for each cluster; identifies name variants by applying name matching techniques to all identified names; and populates a database with the extracted information, learning more about the identified person daily. The Thomson Reuters Open Calais[3] uses Natural Language Processing and machine learning algorithms to extract entities, relations, facts, events and topic code and social tags from submitted texts which are then used for further processing.

Hamborg et al. (2018) developed an open-source, syntax-based system that retrieves an article's main event by extracting phrases that answer the journalistic 5Ws (who, what, when, where and why). Sharma et al. (2013) described 5W1H (who, what, whom, when, where, how) event semantic elements extraction using Semantic Role Labeling (SRL) along with its analysis in their work.

Reschke et al. (2014) have done event extraction using distant supervision approach to extract passenger counts, aircraft types, and other facts concerning airplane crash events. Osoba (2015) developed a system for information extraction of road accidents which extracts information about victims, hospitals and police departments using the designed set of rules that are based on identified patterns. Rules are written in the formalism of the Conceptual Annotations for Facts, Events, Terms, Individual Entities and Relations (CAFETIERE) system. CAFETIERE is an information extraction system designed by a research unit in the School of Computer Science, University of Manchester. (Black et al. 2005).

Arulanandam et al. (2014) describe extracting crime information from online newspaper article by employing Named Entity Recognition (NER) algorithms to identify locations and a Conditional Random Field (CRF) algorithm to classify whether a sentence in the article is a crime location or not. LonMaps (2014) is a work on crime and accident mapping based on news articles, LonMaps, extracts crime/accidents, places, dates and personal names from the news article. LonMaps deals with 4W (what, when, where, and who) of an incident. Places of the incident are displayed on maps and their position is obtained using geocoding. Tanev and Atkinson (2008) presented a real-time news event extraction system for violent and disaster events from online news.

There are plenty of works done on the information extraction through RSS feeds. Han et al. (2009) proposed an efficient algorithm to extract the news article contents from the news pages, that is independent of the page layout. Chy et al. (2014) developed a web crawler to extract useful text from HTML pages of news article contents to construct a full-text-RSS in their work of news classification using Naive Bayes Classifier. Qingcheng and Youmeng (2014) proposed an algorithm to extract content from web pages based on RSS index. They computed the feature of content blocks to obtain the body template with high accuracy.

[2] EMM NewsExplorer, http://emm.newsexplorer.eu/NewsExplorer/readme.html

[3] Thomson Reuters Open Calais, http://new.opencalais.com/

Few works have been done to extract the crisis information from social media posts. Burel and Alani (2018) introduced Crisis Event Extraction Service (CREES), an open-source web API that provides annotations for crisis-related documents, classifies event types (hurricane, flood, etc) and identifies information categories (casualty report, donations and volunteers, etc). The classification was backed by Convolutional Neural Networks (CNNs), which was found to outperform traditional machine learning models. CREES is one of the projects under COMRADES[4], a collective platform for community resilience and social innovation during crisis.

This paper proposes a general system that can be used to extract structured information of casualties from unstructured local news reports in any crisis situation, like disasters and accidents, using Named Entity Recognition, Semantic Role Labeling and regular expressions. Further, locations and involved vehicles are normalized and organized hierarchically. Also, the system facilitates analysis by providing information filtering and visualization interfaces.

METHODOLOGY

In the system, a polling daemon runs daily that polls news from the news sources. The fetched link is checked with the saved list of links that have already been extracted to prevent duplication. The entities from the news article are extracted and stored in a database. Then the extracted information can be filtered and visualized in various forms as needed by the user. The prototype system has been developed in the Django framework in Python and PostgreSQL database was used to store extracted entities.

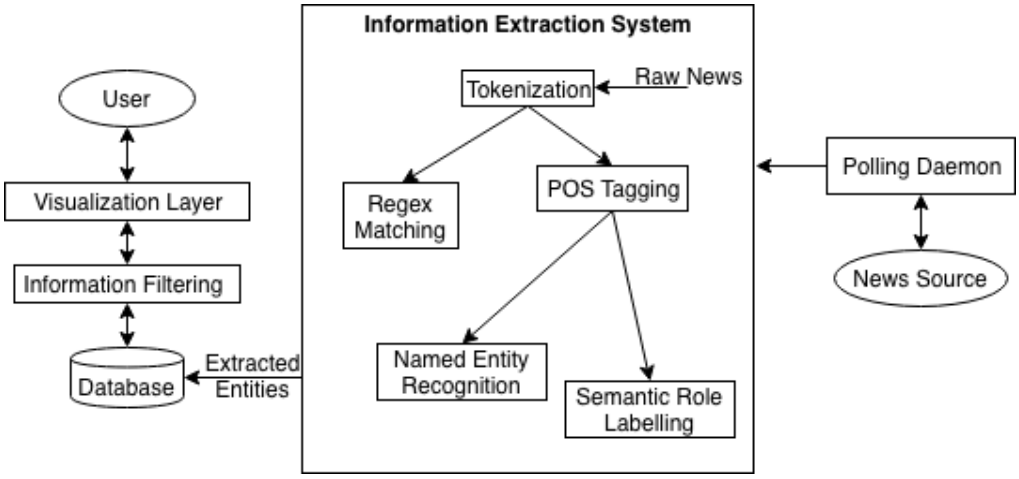


Figure 1. System Architecture.

Data Collection

The online source of news articles used in this work is ekantipur[5], a popular local news site of Nepal. RSS feed of the news articles tagged 'road accident' were fed to the system for information extraction. Since the news website does not support RSS feed, the news is converted to RSS feed using a fetcher named fetchrss[6]. The title and content of each news article from the feed were used.

Usually, news reports follow a common pattern. Every article starts with date of the news which gives the date of the incident. The body usually starts with the casualties involved in the incident specifying the number of people dead and injured along with location where the accident occurred. Vehicles involved are usually mentioned in mid sentences. The latter part usually talks about cause of the accident.

Data Preprocessing

Various methods like tokenization, Parts of Speech (POS) tagging, NER, Lemmatization, Regex matching and SRL are applied on the collected data for the extraction of relevant information.

Sentence tokenization was done using sent_tokenize module provided by Natural Language ToolKit (NLTK).

[4] COMRADES, https://comrades-project.eu/
[5] Ekantipur, http://www.ekantipur.com/
[6] Fetchrss, http://fetchrss.com/rss/5bf76e868a93f84c038b45675bf76e658a93f869028b4567.xml

The module knows what punctuation and characters mark the end of a sentence and the beginning of a new sentence (Loper and Bird, 2002). By looking at the occurrences of those punctuations and sentences the module breaks the paragraph into sentences. Word tokenization was done using word_tokenize module from nltk. It looks for spaces between words to split them.

POS tagging is important to find information regarding vehicle number. It was done using pos_tag module present in the nltk. The module consists of tagger trained in English language which assigns POS tags to the words. To assign tag to a word the POS tagger looks for attributes like if the word starts with a capital letter, has numbers, etc.

NER takes POS tagged sentences as an input to locate and classify named entities in text into pre-defined categories such as the names of persons, organizations, locations, expressions of times, quantities, monetary values, percentages, etc. It was done using NER tagger from nltk. The tagger is trained on English language and can identify named entities by examining its POS tag and the POS tag of word before it.

Lemmatization refers to the conversion of words form their inflectional form into their base form. Lemmatization was done using lemmatizer from spacy library. To convert a word into its base form the lemmatizer removes suffixes.

News articles usually contain date of news published at the beginning of the first sentence. Due to this POS tagging doesn't work as it should so before extracting day, vehicles number, vehicles involved, etc. the date is extracted and removed from the news article.

Dates are written in different formats (yy/mm/dd, dd-mm-yyy, July 1, 2017 etc). Regex matching the specific format is used to extract date. After extraction the date is removed.

Semantic role labeling, sometimes also called shallow semantic parsing, is a process in natural language processing that assigns labels to words or phrases in a sentence that indicate their semantic role in the sentence, such as that of an agent, goal, or result. It consists of the detection of the semantic arguments associated with the predicate or verb of a sentence and their classification into their specific roles. The table below represents the meaning of semantic roles for sentences along with the examples.

Table 1. Arguments in an SRL

Thematic Role	Definition	Example
AGENT	The volitional causer (subject of a sentence) of an event	*the waiter* spilled the soup.
FORCE	The entity that instigates an action, but not consciously or voluntarily.	*the wind* blows debris from the mall into our yards
THEME	The participant most directly affected by an event	only after Benjamin franklin broke *the ice.*
RESULT	The end product of an event	The city built a *regulation-size baseball diamond.*
INSTRUMENT	An instrument used in an event	he poached catfish, stunning them *with a shocking device*
SOURCE	The origin of the object of a transfer event	I flew in *from Boston.*
GOAL	The destination of an object of a transfer event	I drove to *Portland.*

An example of SRL is given below.

Input: “A person died, and four others injured when a micro bus hit them at Jorpati.”

SRL output: [‘A1’: ‘A person’, ‘V’: ‘died’, ‘A0’: ‘A microbus’, ‘V’: ‘hit’, ‘A1’: ‘them’, ‘AM-TMP’: ‘when a micro bus when a micro bus hit them at Jorpati’]

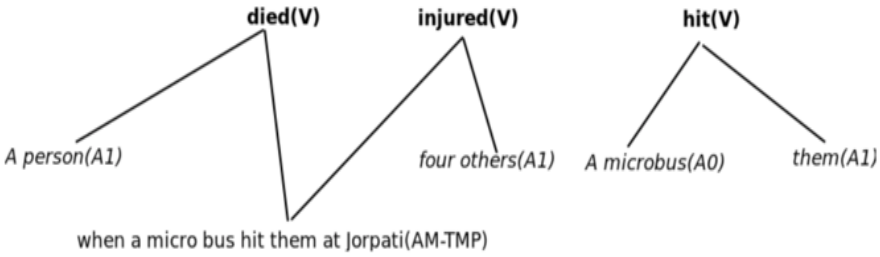


Figure 2. Semantic Parse Tree

Here 'V' refers to the verb, 'A0' refers to the agent and 'A1' refers to patient associated with the verb. AM-TMP is a temporal argument which shows when an action took place. The tag 'V', 'A0' and 'A1' appear in SRL output but they are not semantic roles.

Entities Extraction

The extraction template consists of eight entities which are described below. Entities refer to various fields that are extracted from the news article such as date, vehicle number, number of deaths/injuries, etc.

Death

The Death Field gives information regarding the people who died in the incident. To obtain such information, SRL is used with the death verbs. Death verbs are verbs like die, kill, crush and pass that are present in sentences containing information about death of people. The predicate which matches the death verb provides the required argument. Acceptor ('A0') is chosen as the answer whereas in absence of Acceptor, Accepted argument ('A1') gives death information. Death information is a phrase containing information about the number of deaths. In figure 2, A1 is associated with death verb (die) and A0 is not related with death verb hence A1 is chosen as the phrase related with death and is used for death number extraction.

Word to number conversion algorithm is used to convert the death information extracted from SRL, in previous step, into death number. The death number extraction depends on the extracted death information from the news. During conversion articles ('A', 'An' and 'The') are converted to number one.

For example: "A person died and four others ...". Here the word "A person" is converted to one and hence number of deaths equals one.

Injury

Injury Field gives information regarding the injured people in the incident. Mapping of injury template is carried out with SRL using injury verbs. Injury verbs are verbs like injure, sustain, critical, hurt, wound, harm and trauma that are present in sentences containing information about the injured people. The predicate which matches the verb provides the required argument. Acceptor ('A0') is chosen as the answer whereas in absence of Acceptor, Accepted argument ('A1') gives the injury field. In figure 2, A1 is associated with injury verb hence A1 is chosen as the phrase related with injury.

The injury field information is used to derive Injury Number using the word to number conversion algorithm as in death number conversion. Injury Number extraction depends on the extracted injury information.

Location

The location of the incident is extracted using NER. The word that is tagged as 'GPE' by NER is the extracted location. The locations of Nepal are further organized in a hierarchy. A location tree is constructed with the root node as 'Nepal', and 75 districts as its child nodes. Further, under 'Kathmandu' district node, 150+ locations are defined.

The extracted location is tallied with the location in location tree and the location that matches with the highest degree of similarity is stored. Similarity is obtained by calculating Levenshtein edit-distance between the locations. Similarity check ensures that same location with multiple spellings like 'Koteshowr', 'Koteshwor', 'Koteshor' are stored only once as defined in the location tree. In our tree, we've defined 'Koteshwor' and whenever one of the above three locations is extracted, it checks for similarity and as it passes the threshold of

70%, it is stored as 'Koteshwor' in the database. The 70% threshold was chosen by experimentation.

Vehicle Number

After POS tagging, Regular Expression is used to extract the pattern *<CD>*<CD>, the asterisk represents any character/group of character and <CD> represents a cardinal number which describes the vehicle number in the news report. Vehicle number in Nepal follow a specific pattern <word><number><word><number> and can be captured using the pattern *<CD>*<CD>.

Example: "The bus (Ba 2 Kha 4683), en route to Bardia from Kathmandu, overturned near the Hugdi bridge, said police". Here the bus number, Ba 2 Kha 4683, can be captured using pattern mentioned above.

Vehicle specifies the type of vehicle (bike, car, bus) involved in the incident. For vehicle extraction a gazetteer named 'vehicles' was constructed. The gazetteer contains only lemmatized forms of vehicles. For example, it contains 'bus' but not 'buses'. To find the vehicles, a complete news story is searched to find words whose lemmatized form match the word present in the gazetteer(vehicles) and then the vehicle is categorized into one of three categories two-wheeler, three-wheeler or four-wheeler.

Day

Almost all the news article specifies the day in which the incident occurred in the first few sentences of the news story. Since all seven days of the weekend with the suffix–day we use regex to find the day of the incident.

RESULTS AND ANALYSIS

Results

The extracted information is collected in database as structured data for analysis and visualization. A prototype system has been deployed in a webserver[7]. The site displays the extracted information from the news articles and visualizes it in various forms like graphs, charts and maps.

The main page lists the latest news articles related to road incidents and the extracted items beside the selected news article. Visualization can be done based on the number of incidents and casualties(deaths and injuries). There are filters for location, vehicle types and time range for flexible analysis of incidents.

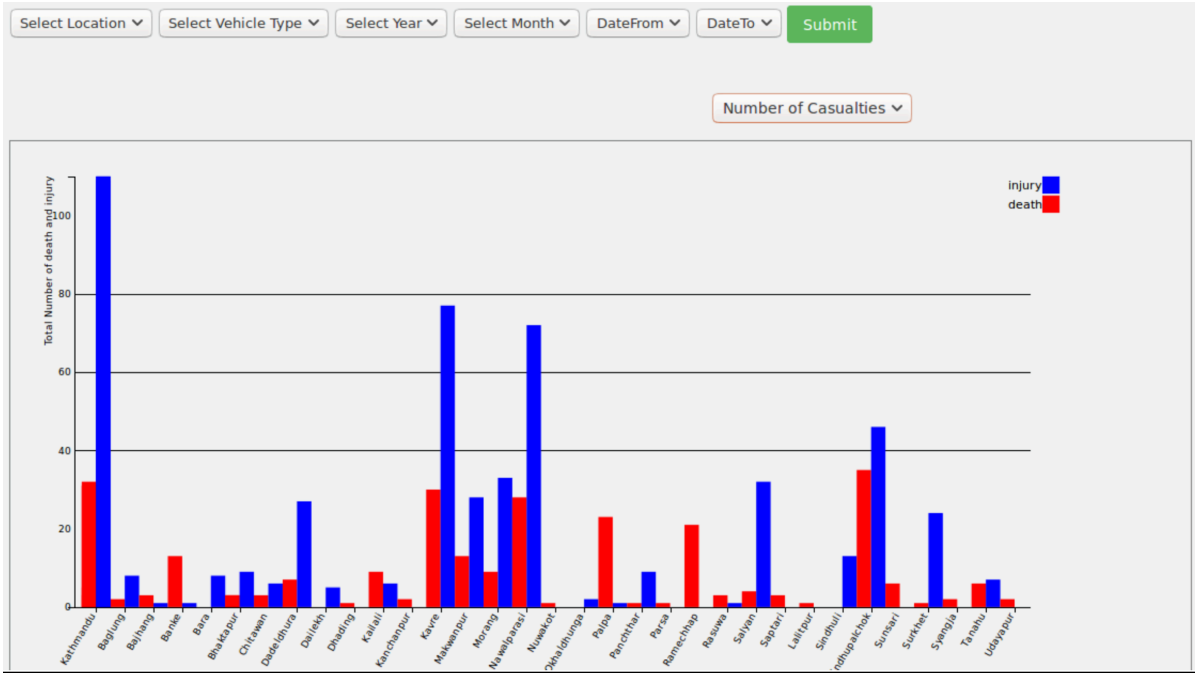


Figure 3. Graph showing district wise casualties.

[7] http://103.5.150.17

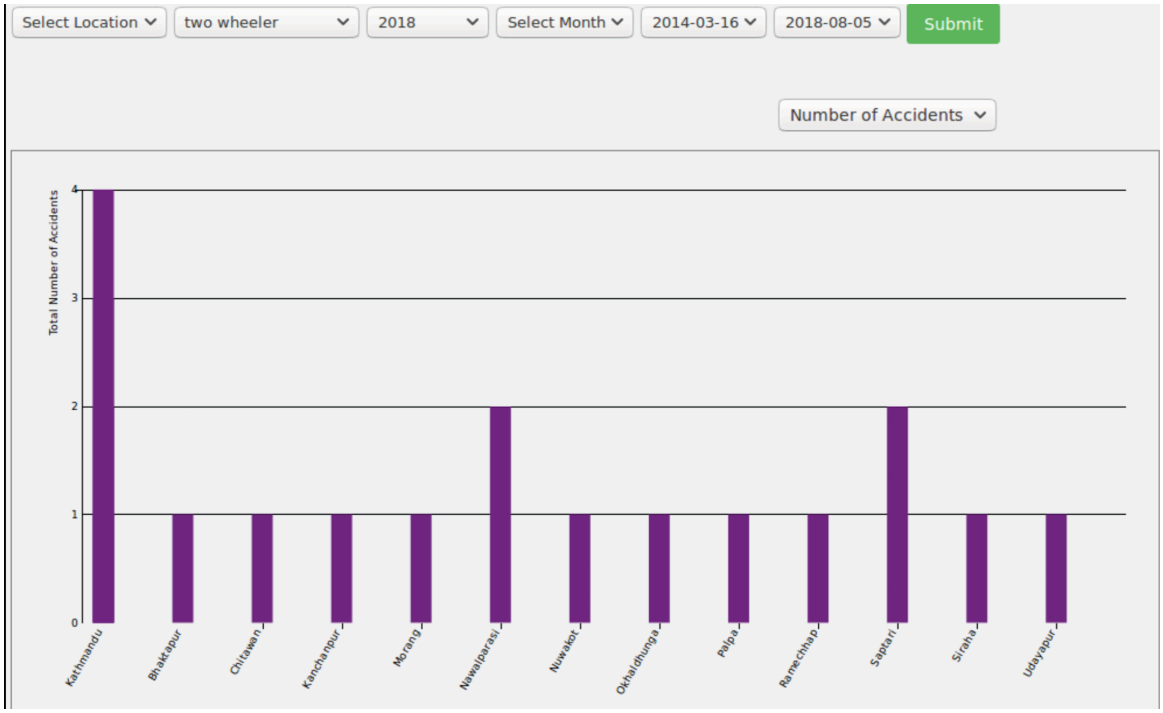
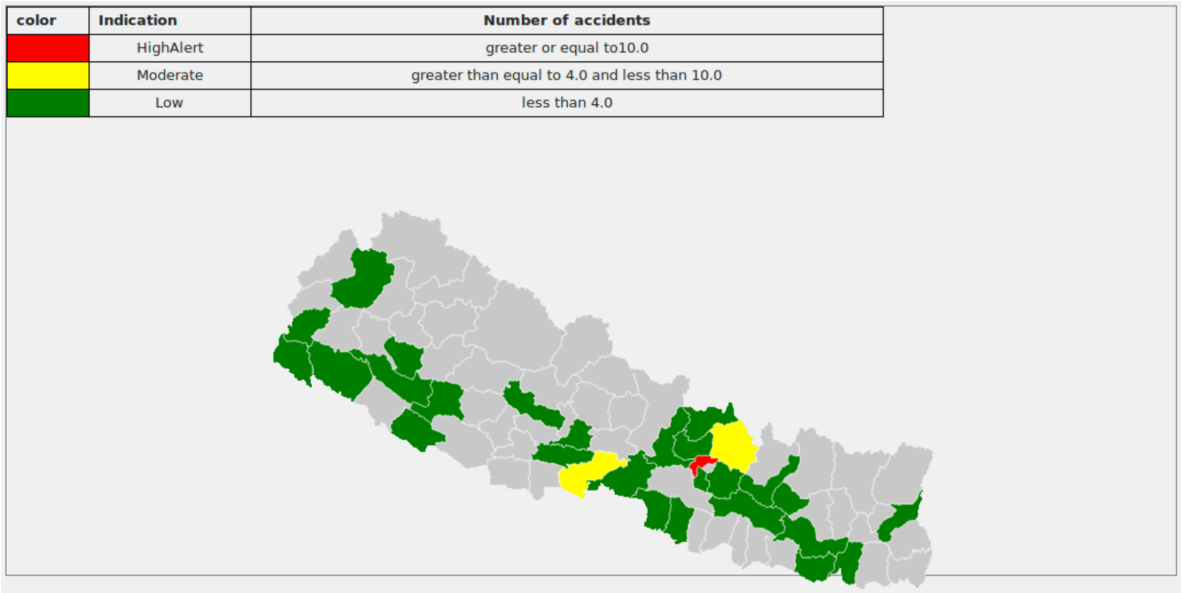


Figure 4. Graph showing district wise two-wheeler incidents in 2018.

Visualization is also possible in the map of Nepal (divided into 75 districts) and map of Kathmandu. In the map of Nepal, the number of incidents is displayed for different districts with three colors: red, yellow and green representing the frequency of incidents, red being the high alert districts. Data from the server is passed in the json format which is processed using D3.js. The threshold value for the alert categories is dynamic and is adjusted according to the total number of accidents.



color	Indication	Number of accidents
	HighAlert	greater or equal to10.0
	Moderate	greater than equal to 4.0 and less than 10.0
	Low	less than 4.0

Figure 5. Map of Nepal showing district wise incidents.

Google Map's API is used to display the specific locations of incidents in the map of Kathmandu. Geocoder was used to obtain the latitude and longitude of a place that was extracted. These values are used to create heatmap using Google Maps API.

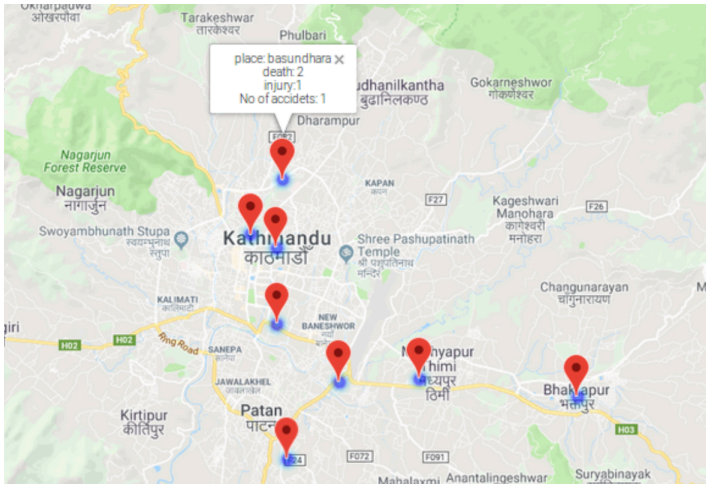


Figure 6. Map of Kathmandu pointing the places of incidents.

Evaluation

The metrics used to evaluate our extraction system is accuracy. Ten entities were used in the analysis, namely death, injury, death number, injury number, location, vehicles involved, vehicle numbers, vehicle types, date and day. The individual accuracy of each extracted entities, the accuracy of each news articles and the overall accuracy of the system is measured. These measures help to test the validity and performance of the designed system.

For an unbiased evaluation of the designed system, 50 news articles were randomly selected. The entities were manually annotated by a group of 10 engineering students and compared with the results obtained from the system to ensure the rules extract the right information. For each entity, the number of correct extractions over 50 news articles was obtained and used in the below equation to calculate the accuracy of individual entities.

$$Accuracy\ of\ entity = \frac{Number\ of\ entities\ with\ correct\ extraction}{Total\ number\ of\ entries}$$

To calculate the accuracy of individual news entries, the two sets of entities, manually annotated and system extracted were compared. The number of correctly extracted entities was obtained and used in below equation to calculate the accuracy of all 50 news entries.

$$Accuracy\ of\ article = \frac{Number\ of\ correctly\ extracted\ entities}{Total\ number\ of\ entities\ in\ an\ article}$$

Finally, the overall accuracy was calculated using the equation below.

$$Overall\ accuracy = \frac{Sum\ of\ accuracies\ of\ all\ news\ articles}{Total\ number\ of\ news\ article}$$

The accuracy of each entity over 50 news articles is as shown in the table below.

Table 2. Accuracy of the Extracted Entities

Entity	Accuracy
Death	94%
Death number	96%
Injury	84%
Injury number	94%
Date	100%
Day	96%
Location	80%
Vehicles involved	88%
Vehicle numbers	96%
Vehicle types	88%

The overall accuracy of the system was found to be 90.8% .

Analysis and Limitations

The system finds the sentences containing pre-defined death and injury verbs and assigns the subject of such sentences as death and injury. The subject of such sentences may not always be the actual deaths and injuries, leading to inaccurate extraction. Similarly, death and injury numbers extracted by the system is not always accurate as it may take other numerals in the sentence as death and injury numbers.

Extraction of date and vehicle numbers is quite accurate as they follow specific patterns while expressing. Extraction of location is least accurate (80%) because there are many locations specified in a news article like the place of incident, the destination of the vehicle, the home address of the victim, the location of the hospital, etc. and system may extract the incorrect location. Also, 75 districts and 150+ places inside Kathmandu are only defined in the location tree. If the extracted location is not in the location tree, extraction is incorrect.

Extraction of involved vehicles is not always accurate as the extracted vehicles should match from the list of pre-defined vehicle gazetteer. Some news articles do not specify the vehicle or have unconventional vehicle names like 'Toyota vehicle', due to which extraction fails. Each vehicle in vehicle gazetteer is categorized as two-wheeler, three-wheeler or four-wheeler, so vehicle type has the same accuracy as vehicles involved.

CONCLUSION AND FUTURE WORK

This paper presented a methodology for the extraction of casualty information from online news articles and demonstrated an online system for the collection, analysis and visualization of the extracted information. Named entity recognition (NER), semantic role labelling (SRL) and regular expression have been used for the extraction purpose. Vehicle and Location extraction have been standardized by using simple vehicle and location hierarchies. The overall accuracy of the system calculated over 50 news articles was found to be 90.8%. Although the system has been implemented for road accidents in Nepal, it can be used in crisis for information extraction from any news involving casualties.

There are still rooms for improvements in terms of accuracy and completeness of the system. Some ongoing and future works are listed below.

- Automatic classification of casualty related news from general RSS news feeds.
- Aggregation of news from multiple sources along with identification and consolidation of duplicate news.
- Updates on the same incident in successive news reports (for example, increase in number of casualties few days after an accident).
- Extraction of the exact cause of the incident for extensive analysis.
- Validation and correction of extracted information to maintain an accurate and up-to-date database.
- Exploration of sentence structures and verbs intention to make more sense from the news.

ACKNOWLEDGEMENT

This work has been supported by the University Grants Commission, Nepal under a Collaborative Research Grant (UGC Award No. CRG-74/75-Engg-01) for the research project "Establishment of a Disaster Telecommunications Research and Educational Facility Advancing a Scientifically Sound Disaster Telecommunication Infrastructure and Processes in Nepal".

REFERENCES

Arulanandam, R., Savarimuthu, B. T. R. and Purvis, M. A. (2014). Extracting Crime Information from Online Newspaper Articles.

Bhandari, A., Maharjan, B. and Pahi, K. (2017). Road Incident News Information Extraction

Black, W.J., McNaught, J., Vasilakopoulos, A., Zervanou, K., Theodoulidis, B., and Rinaldi, F. (2005). "CAFETIERE: Conceptual Annotations for Facts, Events, Terms, Individual Entities, and RElations", *Parmenides Technical Report* TR-U4.3.1.

Burel, G. and Alani, H. (2018). Crisis Event Extraction Service (CREES) - Automatic Detection and Classification of Crisis-related Content on Social Media. *15th International Conference on Information Systems for Crisis Response and Management*, Rochester, NY, USA.

Chy, A. N., Seddiqui, M. H. and Das, S. (2014). Bangla news classification using naive Bayes classifier. *16th Int'l Conf. Computer and Information Technology.*

Hamborg, F., Lachnit, S., Schubotz, M., Hepp, T. and Gipp, B. (2018). Giveme5W: Main Event Retrieval from News Articles by Extraction of the Five Journalistic W Questions, *Transforming Digital Worlds. iConference 2018. Lecture Notes in Computer Science*, vol 10766. Springer, Cham.

Han, H., Noro, T. and Tokuda, T. (2009). An Automatic Web News Article Contents Extraction System Based on RSS Feeds.

Karkee, R. and Lee, A. H. (2001-2013). Epidemiology of road traffic injuries in Nepal.

LonMaps, H. I. (2014). An Architecture of a Crime and Accident Mapping System based on News Articles.

Loper, E. and Bird, S. (2002). NLTK: the natural language toolkit.

Osoba, O. (2015). Information Extraction for Road Accident Data.

Qingcheng, L. and Youmeng, L. (2014). Extracting Content from Web Pages Based on RSS. *16th Int'l Conf. Computer and Information Technology.*

Reschke, K., Jankowiak, M. and Surdeanu, M. (2014). Event Extraction Using Distant Supervision.

Sharma, S., Kumar, R., Bhadana, P. and Gupta, S. (2013). News Event Extraction Using 5W1H Approach & Its Analysis. *International Journal of Scientific & Engineering Research*, Volume 4, Issue 5, May-2013.

Tanev, H., Piskorski, J. and Atkinson, M. (2008) Real-Time News Event Extraction for Global Crisis Monitoring. *Natural Language and Information Systems. NLDB 2008. Lecture Notes in Computer Science*, vol 5039. Springer, Berlin, Heidelberg.

A Unified Approach Integrating Human Shared Mental Models with Intelligent Autonomous Team Formation for Crisis Management

Prithviraj Dasgupta
Computer Science Department
University of Nebraska at Omaha (USA)
pdasgupta@unomaha.edu

Deepak Khazanchi
University of Nebraska at Omaha (USA)
CIEM, University of Agder (Norway)
khazanchi@unomaha.edu

ABSTRACT

Autonomous systems are being exceedingly used to assist humans in various crisis responses scenarios such as earthquakes and nuclear disasters. Because they operate in highly unstructured and uncertain environments, failures are an inherent part of such autonomous systems, and, techniques for making these systems robust to failures arising from computer hardware, software or communication malfunctions are already integrated into their design. However, an important aspect while designing such systems is often times overlooked: how to better coordinate and communicate across distributed, possibly diverse human teams who are working in cooperation with autonomous systems into the design of the autonomous system itself. Unfortunately, this results in limited adoption of autonomous systems in real-life crisis scenarios. In this working paper, we describe ongoing work that attempts to address this deficit by integrating research on shared mental models between humans with techniques for autonomous agent team formation in the context of search and rescue scenarios.

Keywords

Crisis management team, intelligent autonomous system, coalition formation, shared mental model.

INTRODUCTION

Timely and effective responses to disasters are an integral part of every crises management system. Over the past decade, intelligent autonomous systems (IAS) have been employed extensively in different domains to provide efficient and rapid responses to crisis. Examples include search and rescue robots for assisting humans during relief and cleanup activities following natural calamities such as earthquakes, fire and flooding (Erdelj, Krol and Natalio, 2017; Maza *et al.*, 2011; Sable *et al.*, 2018), intelligent agents that can predict damage to infrastructure or presence of hazardous material following disasters such as chemical or nuclear accidents (Sanchez-Cuevas, 2019; Sanchez 2018), and intelligent robots that can perform preventive maintenance tasks such as infrastructure inspection of bridges and buildings or underwater inspection of structures such as ship hulls (Perrot *et al.*, 2015). However, most of these IAS have focused on two areas – 1) how to build sophisticated hardware and software algorithms that can operate autonomously in unstructured environments and uncertain, unprecedented conditions with minimal human intervention, and, 2) how to adapt the IAS' behavior and decision-making so that it can interact in a socially amiable, trustworthy and reassuring manner with the human operating or interacting with it. The design objectives of these IAS have mainly focused on improving the performance efficiency of the IAS, such as the time required and energy (battery) expended to perform its assigned task, and, in some cases, the satisfaction of the human user with using the IAS. Consequently, before deployment, the IAS are tested within simulated environments while interacting with a very limited number of humans. For example, the 2015 DARPA Robotics Challenge (DeDonato *et al.*, 2017) required a humanoid robot IAS to interact only with objects in its environment such as a door handle, fire hose,

stairs, etc. Most importantly, the IAS' performance while interacting with another human or human teams was not validated as a performance criterion in the challenge.

We use this example to highlight that crisis management poses some unique challenges in the context of human-human and human-machine interaction that are usually not encountered in non-crisis or simulated-crisis tasks. Most importantly, crisis management is led by crisis management teams (CMTs) that are drawn from humans with diverse background and expertise including first responders, law enforcement, medical personnel such as doctors and nurses, legal personnel and even citizen volunteers (Yu and Khazanchi, 2015). Each of these individuals is required to work collaboratively with each other and with IAS. Unfortunately, in an unstructured and previously un-encountered scenario like a crisis, when the conventional modes of operation and interaction between human-human and human-machine are drastically altered, the performance of humans and IAS could both get severely degraded. In extreme cases, this could result in delayed or inaccurate responses, or even an inability to respond in crisis scenarios. Our research in this working paper proposes to address this deficiency by utilizing a model for human team formation drawn from coalitional game theory (Shoham and Leyton-Brown, 2009) that would enable IAS to identify and suggest ways to assimilate teams of humans based on their expertise and past performance within a team, as well as adapt the behavior of the IAS while working with an assimilated team of humans, so that the crisis management task could be handled efficiently.

RELATED WORK

Collaboration between human and agent teams has been an active research area in the field of artificial intelligence for almost two decades. Research in this area can be broadly divided into two directions – robot-based systems and multi-agent systems. Disaster robotics research (Murphy, 2014), led mainly by the robotics and engineering community, has made large advances in the past decade with robots being used in dangerous and hazardous tasks including moving concrete chunks, exploring tunnels, diffusing explosives and searching for hazardous material such as nuclear or chemical traces (Recchiuto *et al.,* 2016; Schwarz *et al.*, 2014; Haynes *et al.*, 2015; Leingartner *et al.,* 2018; Kochersberger *et al.*, 2017). However, much of this research has focused on engineering highly dexterous and robust robots that can operate either via teleoperation, or, in some cases autonomously, within adverse and unstructured environments. To the best of our knowledge, robotic disaster response systems that integrate close coordination between teams of humans and teams of robots have not been fielded or researched extensively.

Within the multi-agent systems community, a large portion of the research has focused on the problem of task allocation – how to assign tasks to agents so that the tasks can be performed effectively by the agents, such as reducing the time or effort (e.g., energy or battery) required to complete tasks and reducing the overlap or conflicts between agents while performing tasks. Much of this work has been validated within simulated agent environments closely resembling disaster scenarios (Massaguer *et al.,* 2006). In one of the earliest and seminal works in this direction (Shehory and Kraus, 1998) proposed a distributed coalition formation algorithm, where transportation-like tasks, e.g., moving blocks between locations, were allocated to teams of agents based on their capabilities. Several authors (Klein, Bradshaw, Woods, Hoffman and Feltovich, 2004; Jennings *et al.,* 2014) also laid foundation for effective cooperation between human-agent teams through a set of requirements that a human-agent collective should satisfy. These requirements included defining a mutually agreeable contract between agents and humans to perform a task jointly, being accountable to each other by revealing individual plans and intentions, being flexible to each other's requirements, having intelligent capabilities to interpret and predict each other's decisions and actions, and incentivizing each other's actions by forming coalitions, negotiating goals, managing attention and controlling costs. Future research on human-agent team formation emphasized one or more of these aspects while using a suitable computational framework to represent the interaction between agents and humans. For example, (Ramchurn *et al.,* 2015, Ramchurn *et al.,* 2016) proposed the HAC-ER (Human Agent Collective for Emergency Response) system that uses a framework called multi-agent Markov Decision Processes (MMDP) to formalize the decision making by agents to select tasks within an emergency task response scenario. A novel direction explored in this work was to include input from real-life human-in-the-loop operators to approve and selectively reassign task allocations before dispatching agents to tasks. In (Tambe, Bowring, Jung, Kaminka, Masheswaran, Marecki, *et al.*, 2005), authors observed that unifying different individual frameworks into hybrids were more effective than a single framework for performing collective tasks in disaster scenarios. For instance, integrating belief-desire-intent (BDI) and partially observable Markov Decision Processes (POMDP) frameworks enabled each framework to efficiently perform computations at different levels of information abstraction, for multi-agent task allocation and multi-agent communication in disaster scenarios. Later extensions of this concept were applied to human agent teams in security management scenarios in airports (Pita *et al.*, 2008). Recently, researchers have also focused on integrating human-agent collaboration within the context of massively multi-player online games (MMOGs) (Chan and Vonderer, 2005; Sourmeilis, Ioannou and Zaphiris, 2017). (Hafizoglu and Sen, 2018) explored the evolution of trust in human-

agent team within the context of an online trust game, while (Wicke and Luke, 2017) have modeled human-agent collaboration as a treasure hunting game where each human-agent team has to select different tasks to perform. Several interesting techniques for human agent team formation in disaster response scenarios have also been proposed in the Robocup Simulation Rescue League challenge (RSRL, 2019) where teams of simulated agents representing first responders have to coordinate with each other to perform disaster response tasks. In summary, majority of these research focus on sophisticated algorithms to enable intelligent agents to plan to perform tasks, either collectively or individually, while the human's role is limited to oversight of agents' actions along with intermediate revisions of agent allocations or roles, as necessary. In other words, agents assume the role of human avatars with embedded intelligence while humans assume the role of supervising their avatars. To the best of our knowledge, a unified system, where human teams work alongside agent teams, while sharing work and responsibilities, has not been fully researched. Our proposed work attempts to address this deficit by proposing a framework where agents form coalitions while building a representation of the shared mental model (SMM) of human coalitions or teams within them. This iterated modeling enables agents to quickly identify high-performance human teams and, in parallel, adapt the agent coalitions, so that the capabilities of human-agent teams can be matched for improving task performance. To achieve this, in our proposed solution, we utilize two formalisms rooted in game theory and graph theory called coalition formation in weighted voting game and bipartite graph matching.

SHARED MENTAL MODELS OF CRISIS MANAGEMENT TEAMS

We have previously argued that one of the essential tasks of crisis management is to develop shared mental models (SMM) among teams and members about the crisis at hand, i.e. shared understanding of the task, process, technology and the teams (Yu and Khazanchi (2015). Developing SMM is essential for developing an effective crisis management strategy. Teams can form three types of mental models - information technology mental models, taskwork mental models, and teamwork mental models (Mathieu et al., 2000; Thomas & Bostrom, 2007; Thomas & Bostrom, 2010). A team's IT mental model is the knowledge structure and beliefs held by the team about the information technology capabilities and the usage of these capabilities (Thomas & Bostrom, 2007). A team's taskwork mental model is the knowledge structure and beliefs held by the team about the task goals, steps to accomplish the tasks, and the technologies used to accomplish the tasks (Mathieu et al., 2000). The teamwork mental models refer to the knowledge structure and beliefs held by the team about the team interaction and team members' roles, skills, and knowledge (Mathieu et al., 2000). Assessment of shared *mental models' convergence is mostly focused on measuring the degree to which knowledge structures overlap or are similar among the team members*, i.e. the SMM similarity (Yu & Khazanchi, 2015; Mohammed et al., 2010).

PROPOSED FRAMEWORK: UNIFYING SHARED MENTAL MODEL WITH COALITION FORMATION

In our proposed approach, we posit that more effective human-agent teams can be formed in crisis scenarios if, for a certain task, a team of autonomous agents is paired with a team of humans who have a high possibility of interacting and collaborating efficiently with each other. This step is challenging because, although individual humans might possess desired skills or capabilities for the task, inefficient interaction between humans in a team might degrade the performance of the task (Yu & Khazanchi, 2015). We propose to address this problem using a two-step procedure, as described below.

STEP 1: HUMAN TEAM IDENTIFICATION USING WEIGHTED VOTING GAMES

Given a task to perform in a crisis scenario, the first step in our proposed human-agent team formation technique is to identify a team of individuals with diverse set of expertise suitable for a task, such that the humans in the team can efficiently collaborate with each other to perform the task. The team should also contain only the individuals essential to perform the task, as including unnecessary or superfluous individuals could hinder and delay the task's performance due to inter-team collaboration issues. To quantify the collaboration potential of a set of individuals, we can use mental model measures for *teamwork, taskwork and information technology* to represent the suitability of an individual in a team (Yu & Khazanchi, 2015). These measures of a team's SMM convergence represent different aspects of an individual *i* relevant to functioning as part of a team, as described below:

- Teamwork mental model convergence (ρ_i) represents a team members knowledge structure and beliefs about team interaction and other team members' roles, skills, and knowledge;
- Taskwork mental model convergence (τ_i) represents the knowledge structure and beliefs held by the team about the task goals, steps to accomplish the tasks, and the technologies used to accomplish the

tasks;

- Information Technology mental model convergence (θ_i) represents the knowledge structure and beliefs held by the team about the information technology capabilities and the usage of these capabilities for performing the task.

The values of these suitability parameters could be solicited as input from humans in the team and conditioned with data from their past performances of in teams. In (Yu & Khazanchi, 2015), we have described case studies of using these suitability parameters for a team of individuals performing an information technology management task These parameters are aggregated into a single suitability parameter, called the individual *i*'s *weight*, w_i, and given by:

$$w_i = \alpha_1 \rho_i + \alpha_2 \tau_i + \alpha_3 \theta_i, \qquad \text{subject to, } \alpha_1 + \alpha_2 + \alpha_3 = 1$$

α_1, α_2 and α_3 are preferences over the suitability parameters and could be specified as inputs when a task is assigned to the team. With more experience of a team, these preferences could also be learned from past performances of the team in performing different types of tasks. This weight is then used in a coalition game framework called a weighted voting game (WVG) (Shoham and Leyton Brown, 2009). A weighted voting game denoted by the tuple *(N, **W**, q)* consists of the following attributes:

- *N*: a set of individuals, also called players
- ***W***=*{*w_i*}*:, a set of real-valued weights, where w_i represents the weight or suitability parameter of the *i*-th individual in the team
- *q*: quota, a real valued number representing a minimum threshold value that the combined weights of individuals should satisfy to be able to form a team.

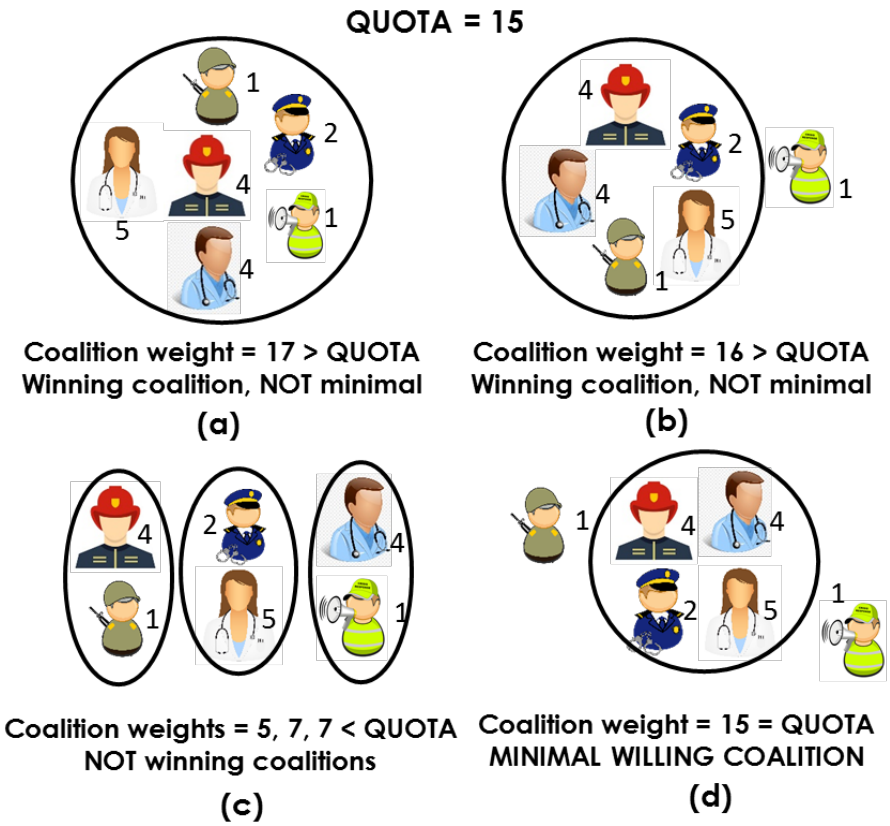


Figure 1. *A Weighted Voting Game (WVG) with quota, q = 15. (a) Grand coalition with all humans is a winning coalition as it satisfies quota, but is not minimal with 6 individuals, (b) Coalition with 5 individuals is also satisfies the quota and is a winning coalition, but is not minimal with 6 individuals, (c) None of the coalitions are winning coalitions as they do not satisfy the quota (d) A minimum winning coalition that satisfies quota and is also minimal with 4 individuals.*

To implement a voting game, all possible subsets of the players are determined. Note that for *N* players there can be 2^N possible subsets. For each subset *S*, in the 2^N possible subsets of the *N* players, the combined weight of the players in *S* is calculated as $\sum_{i \in S} w_i$. Finally, if the combined weight reaches the quota, that is, if $\sum_{i \in S} w_i \geq q$, then *S* is accepted as a winning coalition. The output of a WVG is a set of minimal winning coalitions (MWCs) – the smallest set(s) *S* out of the winning coalitions. Every WVG is guaranteed to have at least one MWC as long as $q \leq \sum_{i \in N} w_i$. An example of a weighted voting game is shown in Figure 1. Here six individuals with different weights or suitability parameter values have to form a team to perform an assigned. The objective of forming the team is to include the essential or smallest set of individuals required to perform the task. A quota value, *q=15,* is calculated for the task and given as input to the WVG. There are multiple winning coalitions in this WVG, two of which are shown in Figures 1(a) and 1(b). But there is only one MWC with four individuals, as shown in Figure 1(d). Figure 1(c) shows sets of non-winning coalitions that are not capable to perform the task as they are unable to reach the quota. Note that, in general, as the number of individuals in the scenario grows, or, as the value of quota, *q*, changes, the number of MWCs can become more than one. In other words, the minimal winning coalition is not unique and multiple teams or coalitions can be output by the weighted voting game. Consequently, the problem of calculating MWCs can quickly become non-trivial to solve as the number of players or individuals, *N,* increases.

In our earlier work (Dasgupta and Cheng, 2016), we had proposed two heuristic-based algorithms with proven performance bounds for calculating the MWC in a WVG, in the context of multi-robot team formation. These algorithms are able to calculate the MWC in polynomial and log-linear time respectively and are able to scale adequately with the number of players or individuals in the scenario. In this work, we plan to adapt those algorithms for identifying suitable human teams that are suitable for effectively performing the assigned task. Our main ongoing research questions in this direction are how to reliably elicit and combine the task suitability parameters from humans for determining the input weights of the WVG, how to address the complimentarity of individual skills or capabilities of humans while forming a team, and, how to calculate a suitable value of the WVG quota input, *q*, from the characteristics or features of a task that needs to be performed.

STEP 2: EFFICIENT HUMAN-AGENT COALITION FORMATION USING PREFERENCE-BASED GRAPH MATCHING

After suitable human teams have been identified in step 1 above, the next step towards forming human-robot collectives is to identify appropriate robots that could be paired with the human teams. In step 2 of our algorithm, we assume that different teams for different sub-tasks are formed by running the WVG algorithm multiple times, once for each sub-task. For example, in a post-earthquake scenario, a team comprising of medics and first responders could be formed to perform a sub-task of providing healthcare to injured persons, while another team comprising of medics and military personnel could be formed to clear debris and rescue persons trapped under rubble. For this, each human team formed from step 1, expresses its desired capabilities from robots in the form of preference values over the set of available robots. For example, a human team comprising of a medical doctor, a firefighter and a law enforcement officer might have a high preference for a group of three robots that can assist respectively with surgical assistance, with clearing and removing debris, and with detecting hazardous substances in the environment. This problem is non-trivial as there could be preference conflicts between human teams for the same set of robots, and, there could also be constraints between robots such as limited number of robots with certain specialized sensors or actuators being available, suitability of pairs of robots to work well with each other, etc. To address this problem, we adopt a framework from computational economics called *matching with preferences* (Pycia, 2012). The objective of the problem is to find a complete matching between two sets of agents such that every agent from one set is paired with exactly one agent from the other set and the preference values between the sets of agents is maximized. For our problem, the two sets of agents are the human teams and robots, and the result is a matching between a human team and a set of robots while maximizing the preference values given by human teams for the robots collectives. This would guarantee that the humans in the human team have the best match of skills and capabilities with the autonomy of the agents in the robot team. Overall, this would result in improved performance of the human-robot collective.

We plan to adapt a bipartite graph matching algorithm from our previous work on configuration formation by robot teams (Dutta and Dasgupta, 2017; Manne and Hiesling, 2007), to address our human-robot team matching problem. The algorithm takes as input a set of team of humans *H* and the set of robots *R* as two disjoint sets. Each human team *i* has a preference parameter p_{ij} that represents the value of a match between the autonomous assistance desired by human *i* and the capability of robot *j*. The objective of the algorithm is to find a set of matchings that maximizes the sum of preference values. Mathematically, this can be represented as $\max \sum_{i \in H, j \in 2^R} p_{ij}$ such that $| p_{ij} | = |H|$. The algorithm works by first enumerating partitions, π, of the robot set, *R*, such that $| \pi | = |H|$. For each partition $\pi_i \in \pi$, it then finds an initial matching where each human team $h \in H$ is matched to its highest preferred set of robots in π. These matchings are removed from the sets of

human teams and robots, and the process continues sequentially until all human teams are matched with sets of robots. An example of a matching between three human teams, each with an ordered set of preferences over sets of robots is shown in Figure 2. The output of the algorithm is a set of matchings between human teams and robots that has the maximal sum of preference values, which guarantees that each human team is paired with its most preferred (but not all) set of robots. This problem is an instance of the set packing problem that is a well known NP-hard problem. Within this framework, some of the research questions we are investigating include speeding up the computation of the maximal matching using recent results from coalition game theory (Hatfield, Kominers and Westcamp, 2017), integrating dependencies or externalities between the robot sets, where the formation of one set of robots affects the preferences of other sets of robots, and, considering the matching problem with dynamically varying preferences of human teams.

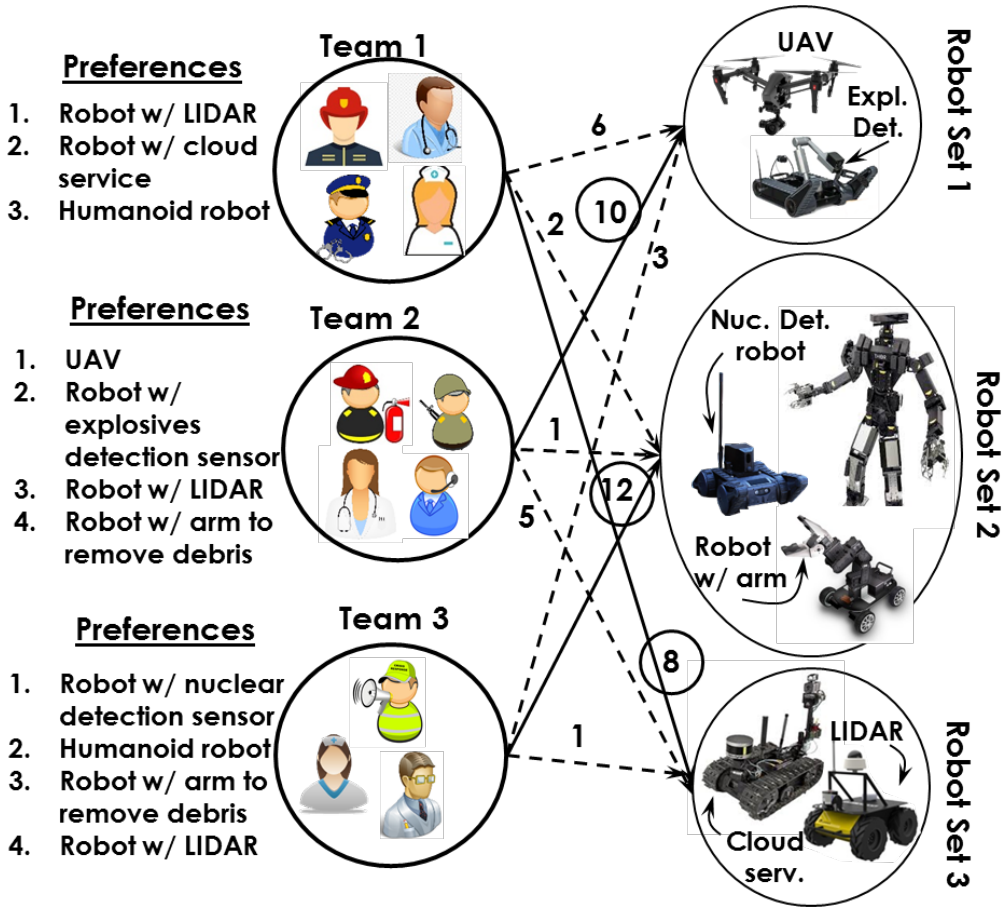


Figure 2. *Matching between three human teams (formed in step 1) with different sets of robots. The values of the different matches to each team are specified by the individuals in the team and shown as edge weights between teams and corresponding robot sets. The matching algorithm returns the maximal matching (shown as solid edges, circled edge weights) between the human team and robot sets that gives the highest combination of preference values. Non-maximal matches, shown with dashed lines, are not selected.*

ONGOING WORK AND CONCLUSIONS

Currently, we are working on formalizing the different research questions and implementing software algorithms in the two-step process for integrating shared mental model (SMM)-based human team formation with human-robot collective formation in the context of crisis management scenario. We plan to evaluate our software algorithms on the Repast multi-agent simulation environment within simulated disaster scenarios, while drawing inspiration from situations and environments featured in the Robocup Rescue Simulation League (Robocup Rescue Simulation League, 2019). In the future, we plan to integrate machine learning-based techniques into our proposed algorithms towards speeding up the computations and making them robust to errors in individuals' reporting of their capabilities and preference for robot assistance. Machine learning algorithms usually require training the model being learned with data from team formation in disaster scenarios. Real-life data for such scenarios will most likely be difficult to obtain. To address this data scarcity problem, we plan to generate virtual, game-like setups that model disaster scenarios, and engage humans to form teams to perform simulated tasks within the game setup. The data generated during these games could then be used to

train the machine learning-based models required by our algorithms. Another direction worth investigating in the future is to form teams with a specified number of humans with certain expertise, e.g., a team with at least five firefighters and two paramedics. Such constraints on team formation could be handled by richer representations of coalition games beyond weighted voting games in step 1 of our algorithm, such as marginal contribution nets (MC-nets). Awareness theory, eliciting human and agent preferences, and dependencies between formed coalitions are additional future directions that we plan to investigate.

Our proposed work investigates a novel direction by integrating human cognitive processes through shared mental models into team formation with autonomous agents. In the future, we envisage that this work will lead to many interesting problems and solutions towards making systems requiring tight coordination and close interactions between human and AI more efficient, reliable and trustworthy in crisis management scenarios.

REFERENCES

Billah, M. M., Ahmed, M., & Farhana, S. (2008, June). Walking hexapod robot in disaster recovery: developing algorithm for terrain negotiation and navigation. In Proceedings of World Academy of Science, Engineering and Technology (Vol. 42, pp. 328-333).

Chan, E., & Vorderer, P. (2006). Massively multiplayer online games. In Playing Computer Games: Motives, responses and consequences. P. Vorderer and J. Bryant (Eds.) Lawrence Erlbaum Associates Publishers, Mahwah, NJ, US 77-88

Dasgupta, P., & Cheng, K. (2016). Dynamic multi-robot team reconfiguration using weighted voting games. Journal of Experimental & Theoretical Artificial Intelligence, 28(4), 607-628.

DeDonato, M., Dimitrov, V., Du, R., Giovacchini, R., Knoedler, K., Long, X., ... & Moriguchi, H. (2015). Human-in-the-loop control of a humanoid robot for disaster response: A report from the DARPA Robotics Challenge Trials. Journal of Field Robotics, 32(2), 275-292.

Erdelj, M., Król, M., & Natalizio, E. (2017). Wireless sensor networks and multi-UAV systems for natural disaster management. Computer Networks, 124, 72-86..

Hafizoglu, F. & Sen, S. (2018, July). The Effects of Past Experience on Trust in Repeated Human-Agent Teamwork. In Proceedings of the 17th International Conference on Autonomous Agents and MultiAgent Systems (pp. 514-522). International Foundation for Autonomous Agents and Multiagent Systems.

Hatfield, J. W., Kominers, S. D., & Westkamp, A. (2017, June). Stability, strategy-proofness, and cumulative offer mechanisms. In Proceedings of the 2017 ACM Conference on Economics and Computation (pp. 673-674). ACM.

Haynes, G. C., Stager, D., Stentz, A., Vande Weghe, J. M., Zajac, B., Herman, H., ... & Brindza, J. (2017). Developing a robust disaster response robot: CHIMP and the robotics challenge. Journal of Field Robotics, 34(2), 281-304.

Jennings, N. R., Moreau, L., Nicholson, D., Ramchurn, S., Roberts, S., Rodden, T., & Rogers, A. (2014). Human-agent collectives. Communications of the ACM, 57(12), 80-88.

Klien, G., Woods, D. D., Bradshaw, J. M., Hoffman, R. R., & Feltovich, P. J. (2004). Ten challenges for making automation a "team player" in joint human-agent activity. IEEE Intelligent Systems, 19(6), 91-95.

Kochersberger, K., Kroeger, K., Krawiec, B., Brewer, E., & Weber, T. (2014). Post-disaster remote sensing and sampling via an autonomous helicopter. Journal of Field Robotics, 31(4), 510-521.

Leingartner, M., Maurer, J., Ferrein, A., & Steinbauer, G. (2016). Evaluation of sensors and mapping approaches for disasters in tunnels. Journal of field robotics, 33(8), 1037-1057.

Manne, F., & Bisseling, R. H. (2007, September). A parallel approximation algorithm for the weighted maximum matching problem. In International Conference on Parallel Processing and Applied Mathematics (pp. 708-717). Springer, Berlin, Heidelberg..

Massaguer, D., Balasubramanian, V., Mehrotra, S., & Venkatasubramanian, N. (2006, May). Multi-agent simulation of disaster response. In Proceedings of the First International Workshop on Agent Technology for Disaster Management (pp. 124-130).

Mathieu, J.E., Heffner, T.S., Goodwin, G.F., Salas, E., & Cannon-Bowers, J.A. (2000). The influence of shared mental models on team process and performance. *Journal of Applied Psychology,* 85, 2, 273-283.

Maza, I., Caballero, F., Capitán, J., Martínez-de-Dios, J. R., & Ollero, A. (2011). Experimental results in multi-UAV coordination for disaster management and civil security applications. Journal of intelligent & robotic systems, 61(1-4), 563-585.

Mohammed, S., Ferzandi, L., & Hamilton, K. (2010). Metaphor no more: A 15-year review of the team mental model construct. *Journal of Management,* 36, 4, 876-910.

Murphy, R. R. (2014). Disaster robotics. MIT press.

Perrot, Y., Gargiulo, L., Houry, M., Kammerer, N., Keller, D., Measson, Y., ... & Verney, A. (2012). Long-reach articulated robots for inspection and mini-invasive interventions in hazardous environments: Recent robotics research, qualification testing, and tool developments. Journal of Field Robotics, 29(1), 175-185.

Pita, J., Jain, M., Marecki, J., Ordóñez, F., Portway, C., Tambe, M., ... & Kraus, S. (2008, May). Deployed ARMOR protection: the application of a game theoretic model for security at the Los Angeles International Airport. In Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems: industrial track (pp. 125-132). International Foundation for Autonomous Agents and Multiagent Systems.

Pycia, M. (2012). Stability and preference alignment in matching and coalition formation. Econometrica, 80(1), 323-362.

Ramchurn, S. D., Wu, F., Jiang, W., Fischer, J. E., Reece, S., Roberts, S., ... & Jennings, N. R. (2016). Human–agent collaboration for disaster response. Autonomous Agents and Multi-Agent Systems, 30(1), 82-111..

Ramchurn, S. D., Huynh, T. D., Ikuno, Y., Flann, J., Wu, F., Moreau, L., ... & Simpson, E. (2015, May). HAC-ER: A disaster response system based on human-agent collectives. In Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems (pp. 533-541). International Foundation for Autonomous Agents and Multiagent Systems.

Recchiuto, C. T., & Sgorbissa, A. (2018). Post-disaster assessment with unmanned aerial vehicles: A survey on practical implementations and research approaches. Journal of Field Robotics, 35(4), 459-490.

Robocup Rescue Simulation League. Online: https://rescuesim.robocup.org/; Last Retrieved January 31, 2019

Sable, A., Wankhede, S., Jadhav, V., & Chavan, S. D. (2017). Fire Fighting Robot for Disaster Management. International Journal of Engineering Science, 12278.

Sanchez, J. M., Cordero, J., Chaudhary, H. M., Sheers, B., & Riobó, Y. (2017). Tactical Communications for Cooperative SAR Robot Missions. In Search and Rescue Robotics-From Theory to Practice. InTech.

Sanchez-Cuevas, P. J., Ramon-Soria, P., Arrue, B., Ollero, A., & Heredia, G. (2019). Robotic System for Inspection by Contact of Bridge Beams Using UAVs. Sensors, 19(2), 305.

Schwarz, M., Rodehutskors, T., Droeschel, D., Beul, M., Schreiber, M., Araslanov, N., ... & Schwarz, D. (2017). NimbRo rescue: Solving disaster-response tasks with the mobile manipulation robot momaro. Journal of Field Robotics, 34(2), 400-425.

Shehory, O., & Kraus, S. (1998). Methods for task allocation via agent coalition formation. Artificial intelligence, 101(1), 165-200.

Shoham, Y and Leyton-Brown, K. "Mutli-Agent Systems: Mathematical, Logical and Game Theoretic Foundations." MIT Press, 2008.

Sourmelis, T., Ioannou, A., & Zaphiris, P. (2017). Massively Multiplayer Online Role Playing Games (MMORPGs) and the 21st century skills: A comprehensive research review from 2010 to 2016. Computers in Human Behavior, 67, 41-48.

Tambe, M., Bowring, E., Jung, H., Kaminka, G., Maheswaran, R., Marecki, J., ... & Paruchuri, P. (2005, July). Conflicts in teamwork: Hybrids to the rescue. In Proceedings of the fourth international joint conference on Autonomous agents and multiagent systems (pp. 3-10). ACM.

Thomas, D.M., & Bostrom, R.P. (2010). Team leader strategies for enabling collaboration technology adaptation: team technology knowledge to improve globally distributed systems development work. *European Journal of Information Systems,* 19, 2, 223-237.

Thomas, D.M., & Bostrom, R.P. (2010). Vital signs for virtual teams: An empirically developed trigger model for technology adaptation interventions. *MIS Quarterly,* 34, 1, 115-142.

Touati, M., El-Azouzi, R., Coupechoux, M., Altman, E., & Kelif, J. M. (2017). A Controlled Matching Game for WLANs. IEEE Journal on Selected Areas in Communications, 35(3), 707-720.

Wicke, D., & Luke, S. (2017, October). Bounty Hunting and Human-Agent Group Task Allocation. In 2017 AAAI Fall Symposium Series.

Yu, X & Khazanchi, D. (2015). Patterns of Information Technology (IT) Adaption in Building Shared Mental Models for Crisis Management Teams. In Proceedings of the ISCRAM 2015 Conference – Palen, Buscher, Comes & Huges, eds.

A Modular Ontology for Semantically Enhanced Interoperability in Operational Disaster Response

Linda Elmhadhbi
University of Toulouse, France
linda.elmhadhbi@enit.fr

Mohamed Hedi Karray
University of Toulouse, France
mkarray@enit.fr

Bernard Archimède
University of Toulouse, France
bernard.archimede@enit.fr

Abstract

Up to now, the world has witnessed how inadequate communication capabilities can adversely affect disaster response efforts. There are various Emergency Responders (ERs) that potentially must work together towards a successful resolution of the disaster. However, the different terminologies and technical vocabularies that are being exchanged between the ERs may lead to a misunderstanding and lack of semantic integrity. Yet, understanding the semantics of the exchanged data is one of the major challenges. The purpose of this work is to define the complex knowledge of the ERs by proposing a common and modular ontology shared by all the stakeholders so as to come up with a common shared vocabulary in order to ensure semantic interoperability between ERs. In this paper, we present POLARISCO and we discuss how it was developed using Basic Formal Ontology as an upper-level ontology and Common Core Ontology as a mid-level ontology to define each module.

Keywords

Semantic interoperability, modular ontology, upper-level ontology, mid-level ontology, disaster response.

INTRODUCTION

When a disaster occurs, a streamlined operational response organization is crucial to handle the disaster effectively. So as to respond within seconds, an appropriate and effective response depends on a detailed plan with clearly articulated roles and responsibilities. It involves a complex network of diverse Emergency Responders (ERs) from different Emergency Response Organizations (ERO) such as firefighters, police, health care services, etc. In fact, numerous after-action reports from major disasters (11 September 2001 and 13 November 2015 terrorist attacks, Hurricane Katrina, etc.) have cited communication difficulties among EROs as a major failing and challenge. The absence of adequate communication and information sharing between the involved actors in disaster response may lead to a break down at the operational response, stakeholders will not know what is happening exactly which will consequently extend the time required to bring a full resolution of the disaster while time is an important factor that has to be considered. Respectively, communication during a disaster is primordial. Information is the most valuable commodity during disaster response. ERs necessitate an ample need for timely information sharing and data exchange to obtain a real-time operational picture of the situation. But, each ERs has its own technical vocabulary. As a result, this discrepancy of information leads to a misunderstanding, a deficiency of semantic interoperability and lack of information sharing among the different actors. This can make the operational response process slow and inefficient. In this work, we aim to define the complex knowledge of the different ERs (firefighters, police, gendarmerie, health care services, etc.) so as to come up with a common shared vocabulary in order to provide the appropriate information at the right place and in the right moment (van Borkulo et al., 2006). Once this task is fulfilled, ERs can operate together and especially can understand each other in any critical situation which is the key to a better operational response (Zlatanova et al., 2004). To do so, a modular ontology

has been developed to explore the semantics of the different ERs in the context of the project POLARISC (Plateforme OpérationnelLe d'Actualisation du Renseignement Interservices pour la Sécurité Civile) (Elmhadhbi et al., 2018). It is a French project which started in 2017. It proposes an interoperable inter-services software solution for reliable and timely information sharing for the operational management of large-scale crisis situations. The focus is about offering to all ERs a real-time operation picture of the situation in order to enable multi-stakeholders and multi-level coordination within the EROs including firefighters, police, gendarmerie, healthcare services, and public authorities. The proposed ontology POLARISCO (POLARISC Ontology) is the core of the system. It will be shared by all the stakeholders in order to enable semantically interoperable information exchange and a common understanding of what is happening on the field. Specifically, it employs Basic Formal Ontology (BFO) as an upper-level ontology and Common Core Ontology (CCO) as a mid-level ontology to present seven ontological modules. This paper is organized as follow. In section2, we overview the main ontologies related to operational disaster response. Section 3 goes into the details of the process of the development of POLARISCO then we present the proposed modules. In section 4, we discuss how POLARISCO is evaluated and is used as a shared vocabulary in a messaging service to enable semantically interoperable information exchange among ERs. Finally, conclusion and future work about our ontology use are presented.

Related work

The different interpretations of data cause semantic heterogeneity. To overcome semantic heterogeneity and to guarantee a consistent shared understanding of the meaning of information, the use of ontologies is crucial (Antunes et al., 2013). Ontologies have been identified as an effective means to implement semantic integration and achieve information interoperability. Ontologies are expressed in a logic-based language, so that accurate, consistent, and meaningful distinctions can be made among the classes, instances, properties, attributes, and relations to reveal the implicit and hidden knowledge in order to understand the meaning of the data. Thus, they offer the richest representations of machine-interpretable semantics for systems and databases**.** They serve as both knowledge representation and as mediation to enable heterogeneous systems semantic interoperability**.** With the increasing amount of data coming from different sources, there is a strong need to determine the meaning of the information to be exchanged precisely enough that a software application can interpret them (Nunavath & Prinz, 2017). So many application of ontologies addresses the problem of semantic interoperability, in which we have different users using various software tools that need to cooperate by exchanging data with unambiguous, shared meaning. In the literature, different types of ontologies and meta-models have been proposed to define the concepts related to disaster response. However, these latter are restricted to one EROs or to a specific case or purpose (Liu et al., 2013).

EMERGEL Ontology, proposed in the context of DISASTER project (Casado et al., 2015), mainly focusses on the mapping of different predefined information's artifacts, information representation and language between countries in Europe. It is composed of a core ontology (events, agents), a transversal module (time and space) and a vertical module (organization's specifications). It reuses the class event of the upper-level ontology DOLCE and other vocabularies such as FOAF (Graves et al., 2007) (peoples in an emergency situation) and the Organization ontology. However, this ontology lacks specific operational information (technical vocabulary of each ER). It can be more useful in decision making at the strategic level rather than the operational level. Moreover, Authors in (Fan & Zlatanova, 2011) looked for solving the problem of spatial data heterogeneity in emergency situations and their transmission to stakeholders by proposing an ontology. SoKNOS ontology (Babitski, 2011) includes resource planning, damages, and geo-sensor information. Regarding EDXL-RESCUER ontology (Barros, 2015), it employs EDXL (Emergency Data Exchange Language) to model the coordinating and exchanging of information with legacy systems. The focus is mainly on alerting people. Another ontology is proposed in (Chehade et al., 2018) for representing situations during rescue operations in order to support situations awareness. It aims to support French first responders in data interpretation during rescue operations. However, on one hand, the proposed ontology is not evaluated and implemented yet, on the other hand, it is dedicated only to firefighters and health care staff. In (Chan et al., 2017), authors proposed PS/EM Communication ontology (Public Safety and Emergency Management) in the context of IDA project (Institute for Defense Analyses). They were based on EDXL (Emergency Data Exchange Language) standards including resource messaging distribution element, hospital availability exchange and common alerting protocol. The ontology was constructed by adding specializations of the BFO and CCO classes. However, this ontology doesn't cover all type of communication between ERs, it is focused on alert messages.

To summarize, during our literature review, we found several ontologies developed in the context of disaster response. However, from one hand, these ontologies don't cover the knowledge of the different involved actors (firefighters, health care services, public order forces, public authorities, etc.) in the disaster response process.

From the other hand, they don't define the technical vocabulary that is used in the operational response such as action centers, functional sectors, operational roles, specific means and so on.

POLARISCO ONTOLOGY

In this work, we propose a modular ontology in order to capture the knowledge of the various stakeholders in a formalism reducible to a logic that expresses logical relationships between the different concepts, and to provide a foundation for semantic interoperability between diverse ERs. The aim is to ensure that all parties share the same extent of such derived information. That is, it aims to establish a common understanding of the shared information.

To build the proposed ontology, a methodology that guides and manages the development process is primordial. In fact, the efficiency of an ontology depends extremely on its development methodology. In (Karray et al., 2012), authors discussed the various methodologies proposed in the literature. In this work, we adopted METHONTOLOGY (Fernández-López et al., 1997) as a development methodology. According to (Corcho et al., 2003), it is the most mature approach to build an ontology. This methodology consists of five main steps of development activities: specification, conceptualization, formalization, implementation, and evaluation.

Specification

We started by identifying the purpose of defining this ontology. To do so, interviews were conducted with stakeholders and emergency experts so as to capture their needs and to analyze their experiences feedbacks. So, POLARISCO is a domain ontology built with the main goal of making the best possible definition of stakeholders' technical vocabulary. It was developed for establishing a common shared conceptualization that defines concepts and their relationships to support semantically interoperable information exchange among ERs involved in the process of operational disaster response. Afterwards, once the objectives are fixed, we used Competency questions (CQs) as a technique to define the ontology specifications. CQs consist of a set of question that the ontology must be able to answer (Grüninger and Fox, 1995). SO, POLARISCO should be able to answer the following defined CQs:
CQs1: When did the disaster [X] take place?
CQs2: Where did the disaster [X] take place?
CQs3: Who were the involved ERs in the intervention [X]?
CQs4: Who was the operational commander of the intervention [X]?
CQs5: Who was the public authority that commanded the intervention [X]?
CQs6: What were the acts of the intervention [X] of the ER [Y]?
CQs7: How many victims were resulting from the disaster [X]?
CQs8: What was the state of the victim [X]?
CQs9: What means were used in the intervention [X]?
CQs10: What are the available means?
CQs11: Where was located the action center [X] of the ER [Y]?
CQs12: Who are the sender and the receiver of the message [X]?
CQs13: What is the type of the message [X]?
CQs14: How many beds are available in the hospital [X]?

Regarding the diversity of ERs' vocabularies and process of intervention which may lead to a complexity during the knowledge conceptualization, we adopted the principles of modularization to build our ontology. Modularization is considered as a way to structure and organizing ontologies. Thus, the construction of a large ontology is based on the combination of self-contained, independent and reusable modules (D'Aquin et al., 2007). The main advantages of such a method, are manipulating smaller ontologies, reducing the complexity of ontologies development, and reusing each module independently. The idea is to develop separate ontological modules so that they could stand alone.
Then, to acquire knowledge about the field of disaster response, we conducted interviews with stakeholders of each EROs (firefighters, health care services, police, gendarmerie and public authorities) and we studied their technical resources and feedback documents to get specific and detailed knowledge about concepts, their properties, and their relationships. On the other hand, we studied many ontologies proposed in the field of disaster response to identify the needed terms including EMERGEL and RESCUER-EDXL, EDXL-RM (Resources Messaging), etc.

Conceptualization

In this phase, the domain knowledge is structured in a conceptual model. We first defined five modules to encapsulate the knowledge of the different involved stakeholders namely firefighters' module, health care services

module, police module, gendarmerie module, and public authorities' module. Then, we defined a message module to represent the needed knowledge to formalize information exchange among ERs and to improve communication capabilities. After that, we built a Glossary of Terms (GT) for each module by referring to the knowledge elucidated during the acquisition step. Terms include classes, properties, instances, and relations that exist among the different classes. As a matter of fact, we found that there are several terms in common between the stakeholders' defined modules which led us to define a core module named PCO (POLARISC Common Core). It englobes the general terms that all stakeholders share (for example disasters, transmission means, victims, etc.) in order to ensure more semantic interoperability between the modules and to facilitate their integration. Next, we selected an upper level ontology as a foundation that provide the most abstract upper level classes to define the more specific information. In (Elmhadhbi et al., 2018), several upper level ontologies have been discussed and we argued our choice of BFO as an upper-level ontology and CCO as a mid-level ontology. In fact, BFO (Arp et al., 2015) is a realist, formal and domain-neutral upper-level ontology, it is designed to represent at a very high level of generality the types of entities that exist in the world and the relations that hold between them. It is utilized as a starting point for the categorization of entities and relationships by more than 250 domain ontology including an ontology-based system used by the US army. As a starting point, BFO uses the term *entity* as a common representation of anything then there are two main division of the class entity: *Continuants* and *Occurrents* in a single framework as a top level distinction between entities. Continuants are entities that persist through time including three axes; objects (Material entity) or and spatial regions (Immaterial entities) as Independent continuant, functions and qualities as Specifically independent continuant and finally, Generically dependent continuant. Occurrents are entities that happen or develop in time such as process. BFO was then supplemented with a set of mid-level ontologies CCO (Rudnicki, 2016) which are the Information Entity Ontology, the Agent Ontology, the Quality Ontology, the Event Ontology, the Artifact Ontology, the Time Ontology, the Geospatial Ontology, the Units of Measure Ontology, the Currency Unit Ontology, and the Extended Relation Ontology.
So, in POLARISCO, classes of each module were classified according to BFO and CCO classes and properties. Figure 1 illustrates the structure of the proposed modules. The purpose behind the use of BFO and CCO is to provide a common ontological foundation for domain ontologies which describe the most general domain-independent categories of reality. It is advantageous to use a common upper layer of well-defined terms to develop the different modules since the ontology will be shared among the involved stakeholders. Indeed, the use of upper-level ontologies facilitates the alignment between several domain ontologies and enable interoperability between them. In other words, if the ontologies to be mapped are driven from a standard upper-level ontology, this will make the mapping task very easy. In addition, upper-level ontologies play the same role as libraries in software programming tasks. Once they are used, one could reuse the defined concepts and relationships and so as to inherit the inferencing capabilities furnished by them. In this way, developing a domain ontology is an easier task that requires less time than usual. Moreover, the aim is to avoid having several incompatible domain ontologies. The usage of upper-level ontologies for integrating information and sharing knowledge among heterogeneous sources has been motivated in various related works (Baumgartner and Retschitzegger, 2006) (Elmhadhbi et al., 2018).

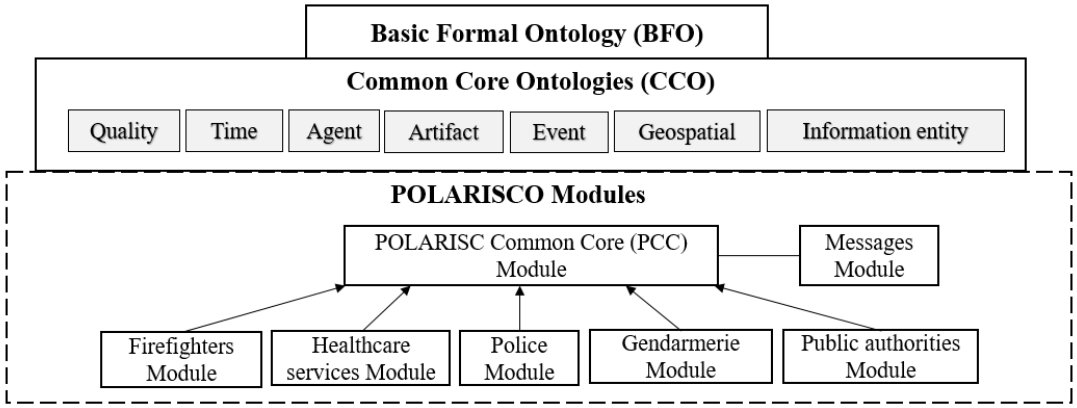


Figure 1. The different modules of POLARISCO

Formalization

After defining the modules and the related GT, in this phase, the conceptual model is transformed into a formal model by establishing relations between concepts. To connect the different concepts, we used a hybrid approach, based on a top-down alignment to the upper-level ontology BFO and the mid-level ontology CCO and a bottom-

up alignment to define classes of stakeholders' module and message module by reusing PCC module. That is to say, we approach in two ways by generalizing high-level concepts to lower levels and by abstracting the low-level data to the higher level concept. So, BFO and CCO are extended to define POLARISCO modules. In fact, CCO reuse the Relations Ontology (RO) (Smith et al., 2005) which is a collection of OWL2 relations intended to be shared among various ontologies. Moreover, another ontology called RO-Bridge has been developed by adding domains and ranges constraints to the object properties defined in RO to be used to relate BFO classes. The relations of RO-Bridge that are reused in POLARISCO are presented in table 1.

Table 1. The reused RO-Bridge relations

Relation	Domain	Range
"has_role"	Independent continuant	role
"has_quality"	Independent continuant	Quality
"supervises"	Person or organization	Person or organization
"has_participant"	Process	Person
"located_in"	Material entity	Spatial region or site
"occurs_on"	Process	Information entity
"is_part_of"	Independent continuant	Independent continuant

In the following, we represent first the various classes and their relationships of PCC module that will be reused to define each stakeholder module. Figures 2 illustrate a partial view of PCC module. Classes reused from BFO and CCO are marked with a prefix. Concerning the occurrent entities, we first defined a *disaster* as a *process*, it can be *natural* (earthquakes, floods, tsunamis, wildfire, tornadoes, etc.) or *human-made* (explosion, terrorist attacks, chemical threats, etc.). *Acts* are performed to manage disasters in an *action center* which is a sub-class of *spatial region*. ERs' acts are done as part of a real *intervention* or *training*. These two classes are integrated as a process. Concerning the continuant entity, an act is characterized by a *type* depending on the nature of the disaster. Furthermore, a *role* is accorded to each *organization member*. An organization member or an ordinary person can have the role of a *victim*. A *victim* is characterized by a *state*. In addition, *infrastructure* (hospitals and digital radio networks), *mean* (transmission mean such as radio or telephone) and *equipment* (beds) are defined as an *artifact*.

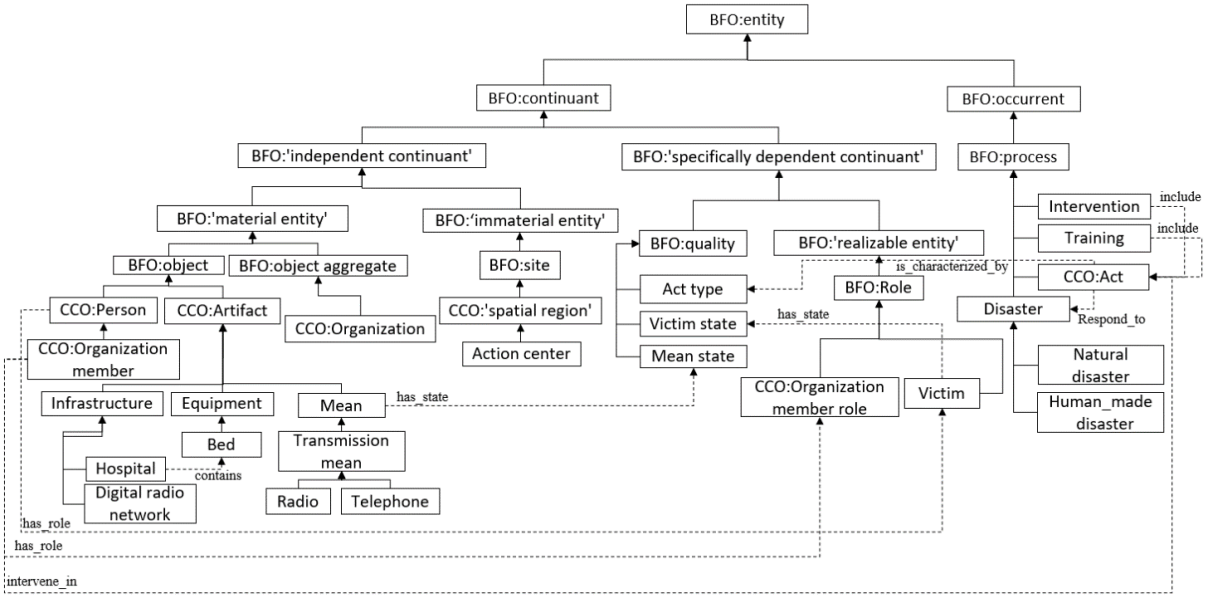


Figure 2. POLARISC Common Core (PCC) module

Concerning the stakeholders' modules, we formalized each one according to the PCC module. That is, we used PCC module as a starting point, and then we added the appropriate concepts related to each module. So, we defined the technical vocabulary of each ER (firefighters, health care services, police, gendarmerie, and public authorities) including mainly roles, commandment, and operational members, services, acts, means and their functions and availability, action centers, etc. Furthermore, we added the interventions' needs in terms of means and staff. Figure 3 shows a partial view of the stakeholders' modules.

Indeed, one of the principles to respect in building useful ontology is that any term of the ontology should be defined in a consistent manner (Arp et al., 2015). So, we defined annotation for each class (definition, the signification of the abbreviation, labels, etc.). Then, we defined relations that exist among the various modules and especially the equivalent classes. Each module has at least one relation with other modules. For example, the public authorities' module is linked to the rest of the stakeholders' modules with the relationship "supervises". That is to say, the interior minister supervises the commandment member of each ER. In fact, annotation and equivalent classes will have a key role later in the messaging service. Specifically, it will enhance communication capabilities and enable the transformation of the exchanged information from one stakeholder to another. So, each stakeholder will receive information according to his own vocabulary.

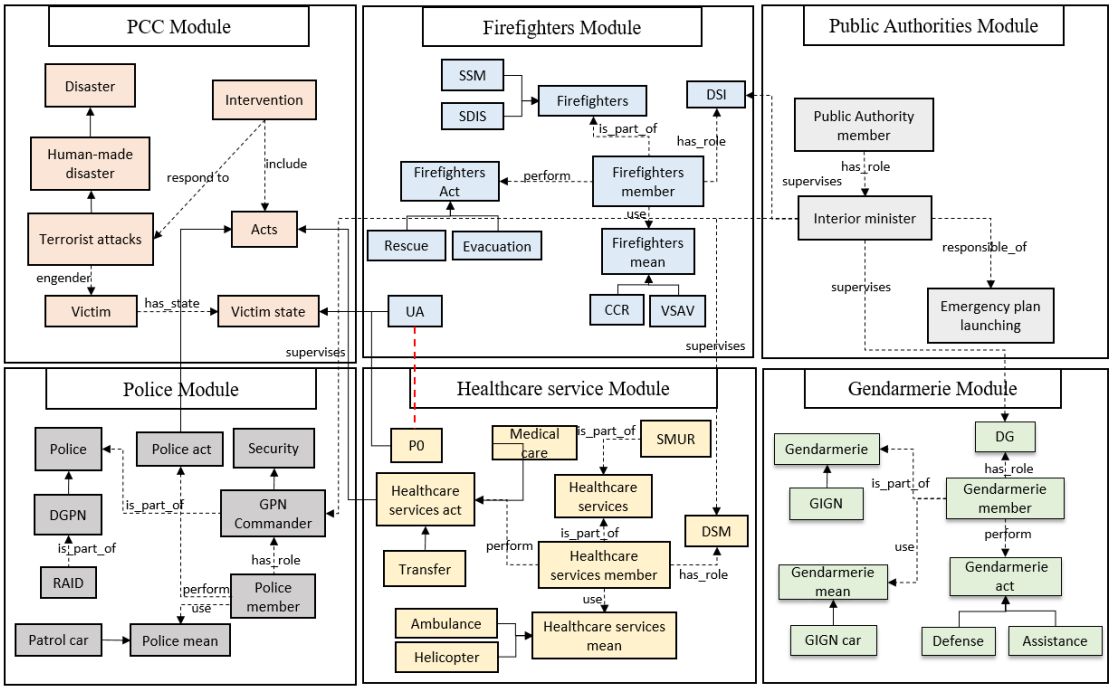


Figure 3. Partial view of stakeholders' modules

Concerning the message module, it is related to the PCC module and subsequently to the stakeholders 'modules. To defined it, we reused classes from PS/EM Communication Ontology (Chan et al., 2017). Authors were based on EDXL-RM (Emergency Data Exchange Language-Resource Messaging) standards. Figure 4 shows a partial view of the proposed module. The reused classes are marked with the prefix EDXL. We defined a *message* as an *information bearing artifact*. There are three different types of messages that could be exchanged among ERs; *informative message* (*information message*, *alert message*, *report message*, etc.), request message (*backup message*, etc.) and *response message (*a response message "is_about" a request message). In addition, a message is characterized by a state (*treated*, *untreated* or *ongoing*), a confidentiality (*public*, *private* or *limited*) and a degree of criticality of the information to be exchanged (*extreme*, *moderated* or *secondary*). Moreover, a message is identified by an *ID* and the same for *sender* and *receiver* which are defined as an *agent*.

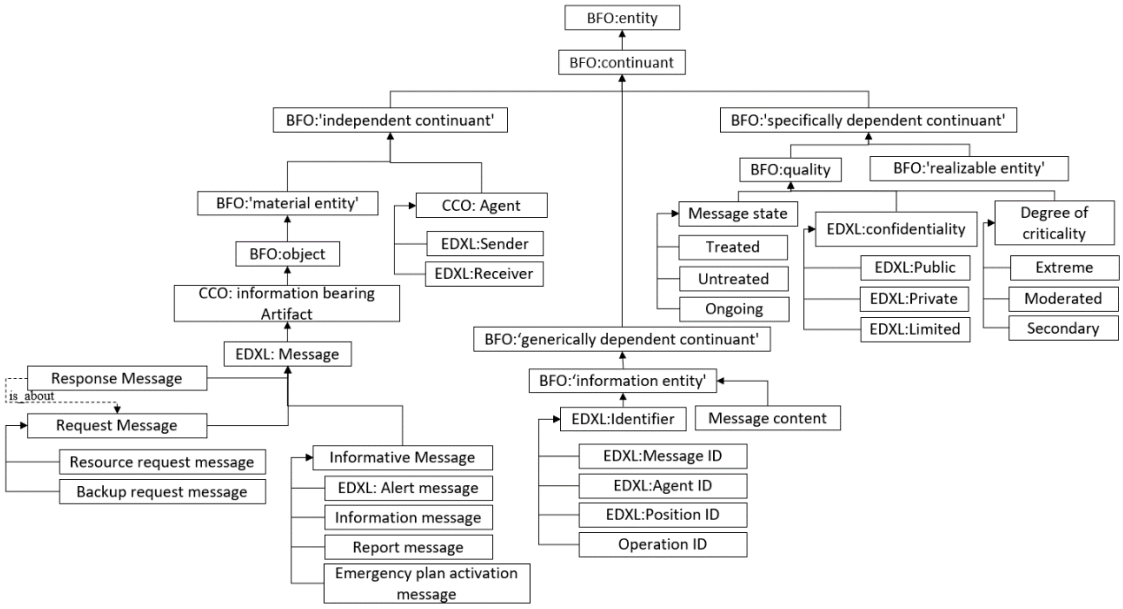


Figure 4. Message module

Implementation

The proposed formalization models are encoded in the ontology implementation language OWL and implemented using Protégé. It is an open source ontology editor and framework that propose a set of tools to construct ontologies. It facilitates the definition of classes, properties, and rules, visualization and reasoning. First, we reused BFO and CCO to build the PCC and message modules by utilizing the "owl: import" feature of OWL2. Second, we imported PCC to construct the stakeholders' modules. Then the different modules are merged together and integrated into one ontology "POLARISCO". Table 2 presents the classes and relations of the global ontology.

Table 2. Classes and relations of POLARISCO

Ontology	Number of Classes	Number of Relations
Developed ontology		
POLARISCO	447	25
Imported ontology		
BFO	27	-
CCO	195	152
Total	669	177

Evaluation

To evaluate the proposed ontology, from one hand, the consistency of POLARISCO modules was checked using the reasoner HermiT, which is an OWL2 reasoner included in Protégé. The aim is to ensure that the constructed ontology don't contain logical incoherencies or modeling issues such as contradictory relations between classes. On the other hand, to check if the ontology responds to the fixed specifications, we translate the CQs into SPARQL (Simple Protocol and RDF Query Language) language so as to query the ontology. To do so, the ontology was instantiated using feedbacks and documents of "Richter-65". It is an exercise of simulation of an earthquake in France which involves all the ERs.

One of the examples of the obtained results are presented in figure 5 to answer the following CQ: "Who are the operational commanders of the involved ERs in "Richter-65"?"

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX po: <http://www.semanticweb.org/linda/ontologies/2017/10/POLARISC1#>

SELECT    ?Rôle_de_commandememnt    (?Membre_des_pompiers as ?Membre)
WHERE {   po:Richter_65    po:commanded_by    ?Membre_des_pompiers.
          ?Membre_des_pompiers    po:has_role    ?Rôle_de_commandememnt.
          }
```

Rôle_de_commandememnt	Membre
COS	Jacquin
DSM	Durand
Directeur_GPN	MORVAN
DG	Lizurey

Figure 5. SPARQL query and result of the CQ

To summarize, we proposed POLARISCO, a modular ontology that define ERs knowledge and the needed information to ensure a semantically interoperable information exchange among stakeholders. It concerns firefighters, health care services, police gendarmerie and also public authorities. The modular conceptualization of the ontology enables its reuse as separate modules. One strength point of the development of the ontology is the fact that the process of collecting information, testing and evaluating the ontology was made referring to stakeholders. In addition, the designed ontology is validated by the emergency experts. POLARISCO will be used in English or French, we are working on labelling each class of the ontology in the two languages. The global modular ontology described in this paper is available in OWL format on GitHub: https://github.com/LindaElmhadhbi/POLARISC-Ontology.

CONCLUSION AND FUTURE WORK

In operational disaster response, there are various ERs from different EROs that potentially must work together towards a successful resolution of the disaster. However, communication is still ineffective since each ER uses his own technical vocabulary without realizing that they can be referring to different concepts. As a result, a different interpretation of data may happen that handicap the response process and cause slower decision making. To resolve semantic heterogeneity among ERs, there is an ample need to define the complex knowledge of the different stakeholders. Therefore, the purpose of this work is to come up with a common shared vocabulary in order to ensure semantically interoperability between ERs. So, we proposed POLARISCO, a modular ontology that enables semantically interoperable communication among stakeholders a comprehensive operational picture of the field. As future works, the proposed ontology can be extended to be used in the field of smart cities once it is aligned with existing standards and well-known models for smart city data. In addition, the ontology will be tested by means of a concrete use case to show how a communication act can be improved across different ERs and practitioner's feedbacks will be presented.

ACKNOWLEDGMENTS

This research was conducted as part of the POLARISC (Plateforme OpérationnelLe d'Actualisation du Renseignement Interservices pour la Sécurité Civile) project. It was funded by the regional operational program FEDER/FSE « Midi-Pyrénées et Garonne 2014-2020 » as part of the call for projects "Easynov2016".

REFERENCES

Antunes, G., Caetano, A., Bakhshandeh, M., Mayer, R., & Borbinha, J. (2013). Using ontologies to integrate multiple enterprise architecture domains. In International Conference on Business Information Systems (pp. 61-72). Springer, Berlin, Heidelberg.

Arp, R., Smith, B., & Spear, A. D. (2015). Building ontologies with basic formal ontology. Mit Press.

Babitski, G., Bergweiler, S., Grebner, O., Oberle, D., Paulheim, H., & Probst, F. (2011). SoKNOS–using semantic technologies in disaster management software. In Extended Semantic Web Conference (pp. 183-197). Springer, Berlin, Heidelberg.

Baumgartner, N., and Retschitzegger, W. (2006) A survey of upper ontologies for situation awareness. In Proc. of the 4th IASTED International Conference on Knowledge Sharing and Collaborative Engineering, St. Thomas, US VI, 1-9.

Barros, R., Kislansky, P., Salvador, L., Almeida, R., Breyer, M., & Pedraza, L. G. (2015). EDXL-RESCUER ontology: Conceptual Model for Semantic Integration. In ISCRAM.

Casado, R., Rubiera, E., Sacristan, M., Schütte, F., & Peters, R. (2015). Data interoperability software solution for emergency reaction in the Europe Union. Natural Hazards and Earth System Sciences, 15(7), 1563-1576.

Chehade, S., Matta, N., Pothin, J. B., & Cogranne, R. (2018, October). Data Interpretation Support in Rescue Operations: Application for French Firefighters. In 2018 IEEE/ACS 15th International Conference on Computer Systems and Applications (AICCSA) (pp. 1-6). IEEE.

Chan, S., Haugh, B. A., Loaiza-Lemos, F. L., Wartik, S. P. (2017). Public Safety and Emergency Management Communications Ontology. IDA Document D-8583

Corcho, O., Fernández-López, M., & Gómez-Pérez, A. (2003). Methodologies, tools, and languages for building ontologies. Where is their meeting point? Data & knowledge engineering, 46(1), 41-64.

D'Aquin, M., Schlicht, A., Stuckenschmidt, H., & Sabou, M. (2007). Ontology modularization for knowledge selection: Experiments and evaluations. In International Conference on Database and Expert Systems Applications (pp. 874-883). Springer, Berlin, Heidelberg.

Elmhadhbi, L., Karray, M. H., & Archimède, B. (2018). An Ontology-based Emergency Response System for Interoperability in a Crisis Situation in Smart Cities. Enterprise Interoperability: Smart Services and Business Impact of Enterprise Interoperability, 421-427.

Elmhadhbi, L., Karray, M. H., & Archimède, B. (2018). Towards an Interoperable Operational Emergency Response System for Large-Scale Situations: POLARISC. ISCRAM 2018

Elmhadhbi, L., Karray, M. H., & Archimède, B. (2018). Toward the use of upper level ontologies for semantically interoperable systems: An emergency management use case. In *Enterprise Interoperability VIII*.

Fan, Z., & Zlatanova, S. (2011). Exploring ontologies for semantic interoperability of data in emergency response. Applied Geomatics, 3(2), 109-122.

Fernández-López, M., Gómez-Pérez, A., & Juristo, N. (1997). Methontology: from ontological art towards ontological engineering.

Graves, M., Constabaris, A., & Brickley, D. (2007). Foaf: Connecting people on the semantic web. Cataloging & classification quarterly, 43(3-4), 191-202.

Grüninger, M. & Fox, M.S. (1995). The role of competency questions in enterprise engineering. In Benchmarkingâ˘AT˘Theory and practice (pp. 22–31). Springer.

Karray, M. H., Chebel-Morello, B., Zerhouni, N., (2012). A formal ontology for industrial maintenance. Applied Ontology. 7, 269-310.

Liu, S., Brewster, C., & Shaw, D. (2013). Ontologies for crisis management: A review of state of the art in ontology design and usability. In ISCRAM.

Nunavath, V., & Prinz, A. (2017). Data Sources Handling for Emergency Management: Supporting Information Availability and Accessibility for Emergency Responders. In *International Conference on Human Interface and the Management of Information* (pp. 240-259). Springer, Cham.

Rudnicki, R. An Overview of the Common Core Ontologies, CUBRC, INC (2016)

Smith, B., Ceusters, W., Klagges, B., Köhler, J., Kumar, A., Lomax, J., Mungall, C., Neuhaus, F., Rector, A.L., Rosse, C., (2005). Relations in biomedical ontologies. Genome Biol. 6, R46.

Van Borkulo, E., Scholten, H. J., Zlatanova, S., & van den Brink, A. (2005). Decision making in response and relief phases. In Geo-information for Disaster Management, First International Symposium on Geo-information for Disaster Management, Delft, 31-23 March 2005 (pp. 47-53).

Zlatanova S, Oosterom P van, Verbree E (2004). 3D technology for improving Disaster Management: GeoDBMS and positioning, S. in Proceedings of the XXth ISPRS congress, Istanbul, Turkey, 12th - 24 July, 6 p.

Track 11.

Community Engagement & Healthcare Systems

Chairs

Zeno Franco, *Medical College of Wisconsin, USA*

Bas Linjse, *Radboud University, Netherlands*

Reem Abbas, *Auckland University of Technology*

Sheikh Iqbal Ahamed, *Marquette University, USA*

Taxonomy of Community Interaction in Crises and Disasters

Daniel Auferbauer
AIT Austrian Institute of Technology
daniel.auferbauer@ait.ac.at

Christoph Ruggenthaler
AIT Austrian Institute of Technology
christoph.ruggenthaler@ait.ac.at

Gerald Czech
Austrian Red Cross
gerald.czech@roteskreuz.at

Ivan Gojmerac
AIT Austrian Institute of Technology
ivan.gojmerac@ait.ac.at

ABSTRACT

Taxonomies are integral to systems engineering, as they structure our knowledge of a field and so provide the foundation for technological development. We contribute such taxonomies for the field of Community Interaction and Engagement in Crisis and Disaster Management, which represents the interface between members of the public who commit to relief efforts and established organisations that have a pre-defined role in crisis management. These actors are unified in their purpose to help those in need, but also set apart by their organisational structures and modes of operation. We classify the actors of Community Interaction and Engagement, as well as the interactions between them. Our contribution outlines areas where the application of Information and Communication Technology can offer benefits to Community Interaction and Engagement.

Keywords

information and communication technology, sociotechnical systems, crisis and disaster management.

INTRODUCTION

Citizens' behaviour in the event of a disaster or crisis has been subject to academic interest for decades. The earliest research on this matter dates back to the Halifax harbour munition explosion disaster (Prince, 1920). Later, the research conducted at the Disaster Research Center of the Ohio State University investigated the sociological and organisational aspects of the involvement of citizens in *Crisis and Disaster Management* (CDM). Especially the works of Dynes and Quarantelli and their classification of organisation types are still often referred to. Since the turn of the century, the introduction of global and ubiquitous *Information and Communication Technology* (ICT) provides affordable means of rapid coordination, resulting in new forms of cooperation. The emergence of volunteer groups, which independently organise and operate through online social media and digital communication services (Liao et al., 2016; Starbird and Palen, 2013; Twigg and Mosel, 2017), attests to the influence of ICT on CDM. Citizens can now react to an incident with great reach and speed (Palen and Liu, 2007).

For this paper, we denote as *Community Interaction and Engagement* (CIE) the confluence of such committed members of civil society and the established entities of disaster relief: emergency organisations, public authorities and civil defence. Citizens and communities have been overlooked as important actors in CDM, as the field was long considered subject to the sole command and control of governmental bodies or military forces (Dynes, 1994). Although communities of civil society and their efforts in crisis and disaster relief have long been part of the research discussed at ISCRAM, comprehensive taxonomy of their interactions with other actors has not been attempted. Addressing this gap in the existing body of literature, we propose two taxonomies, of actors and their interactions, to outline CIE.

As primary contribution, our description of Community Interaction and Engagement provides a basis for determining which interactions can be supported through ICT, and facilitates a profound design of technological systems to achieve as much.

ORIGINS

We draw on insights from our own research efforts as well as related literature. Two research projects were especially influential on this paper:

1) 'Resilience Enhancement by Advanced Communication for Team Austria' (RE-ACTA[1]), concluded in 2015, aimed to bring the structure and best practices of a successful national volunteer programme to new media. Outcomes suggested that the lateral information exchange among volunteers and their individual initiative should be considered when designing for CIE (Auferbauer et al., 2016; Auferbauer and Tellioğlu, 2017).
2) 'New media technologies in crisis and disaster management for enhancing the resilience of communities' (MEDIATOR), initiated in 2015, investigates the interaction between self-organising volunteers and the established organisations for crisis and disaster management in the context of the European migration crisis (2015). MEDIATOR focuses on interactions between formal and informal actors, as described from their respective viewpoints.

Both research projects follow(ed) an empirical approach that derives ICT for CIE through induction, based on the analysis of qualitative data from interviews and field observation. Representatives of formal organisations were involved in both projects, while unaffiliated and pre-registered volunteers participated in one project each. From RE-ACTA, we inferred a need to differentiate in more detail the various forms of volunteer engagement; a classification into 'emergency organisations' and 'volunteers' did not appear to sufficiently cover the actors of relief efforts. Data from MEDIATOR confirmed this by revealing well-organised and structured groups of volunteers that were active on a long-term basis outside the formal response system and beyond ephemeral actions of spontaneous groups. Ultimately, both projects prompted us to attempt a comprehensive taxonomy of interactions between the emergency response system and civil society as a foundation for the application of ICT in CDM.

RELATED WORK

A typology of factors that influence multi-agency coordination has previously been proposed to the ISCRAM community by Curnin and Owen (2013). Their typology describes attributes of successful communication for coordination; whereas our present work aims to map out the purpose and participants of interactions. We consider the two synergistic, as the work of Curnin and Owen can be applied to each of the interactions we detail herein. Further, communication structure, channels and content during incident response have been described in a detailed, scenario based manner (Eide et al., 2013); primarily considering information exchange within the formal emergency response system, but lending some concrete examples for parts of the abstract taxonomy presented herein. Liu et al. (2013) provide a comprehensive review of existing ontologies and their applicability for CDM; within their conceptualisation of subject areas, our present work would likely concern 'processes', for which the authors report no ontologies similar to the one proposed herein.

TAXONOMY OF ACTORS

In this work, we distinguish between actors based on their socialisation in the field of CDM, meaning their internalisation and incorporation of norms, values and social behaviours related to CDM. In Table 1, actors of CIE are shown in two categories, each ordered by increasing level of socialisation.

Together with established organisations, volunteers play an important role in relief efforts. However, the definition of 'volunteer' varies between organisations, context of activity and cultural background (Whittaker et al., 2015). As *unaffiliated volunteer* we define a person who is participating in relief efforts, but is not part of an organisational structure that has a predefined role or obligation in CDM planning. The unaffiliated volunteer acts outside of the formal crisis management system and has thus been referred to as 'informal volunteer' (Whittaker et al., 2015). The *pre-registered volunteer*, on the other hand, has signed up with a volunteer programme or platform (possibly managed by a formal organisation, see below) and has, as such, become part of an organisational structure (Neubauer et al., 2013). However, they have not entered a long-term membership association with a formal organisation for crisis management or disaster relief. *Affiliated supporters*, on the other hand, hold membership status with a formal CDM organisation, thus being subject to different obligations (e.g. mandatory training or adhering to the chain of command). They may be volunteers, receiving little to no monetary compensation for their contribution, or employed by the organisation they are members of, contributing as part of their gainful employment. Lastly, *affiliated decision-makers* are differentiated from

[1] http://www.kiras.at/en/financed-proposals/detail/d/re-acta/

affiliated supporters by being afforded enough authority through embodied cultural capital to make tactical or strategic decisions within the organisational structure. While these roles may be filled by volunteers, the term 'volunteer' traditionally has included primarily those that we have classified here as affiliated. However, unaffiliated volunteers and their consideration in crisis and disaster relief have increasingly gained attention (Barsky et al., 2007; Harris et al., 2017; Neubauer et al., 2013; Twigg and Mosel, 2017; Whittaker et al., 2015). They may be regarded as disturbance, as valuable resources or as critical factor for recovery, depending on the observer's viewpoint (Rogstadius and Teixeira, 2013).

Individual actors	
Unaffiliated volunteers	Persons intending to participate spontaneously in relief efforts without prior affiliation to formal emergency organisations.
Pre-registered volunteers	Persons who have signed up for a programme or initiative and conduct their activity within its organisational boundaries.
Affiliated supporters	Persons who have membership status in a formal CDM organisation, who conduct their activity along its organisational structure.
Affiliated decision-makers	Persons who have membership status in a formal organisation, who are afforded decision making in its organisational structure.
Composite actors	
Emergent groups	Formed through the self-organisation efforts of persons as reaction to a crisis or disaster event.
Supporting organisations	Established organisations that participate in relief efforts, but do not engage in such activity as part of their regular operations.
Formal CDM organisations	Established organisations whose regular objectives include crisis and disaster management activities.

Table 1 Taxonomy of Actors in Community Interaction and Engagement (Summarised)

Individual actors, as they are outlined above, can form compound entities with a complex organisational structure. Most prominent among these are the established *formal CDM organisations*, whose regular functions include responsibilities in disaster relief. Emergency organisations, humanitarian aid agencies, civil defence and public authorities all have a pre-defined role in CDM; legally and socially, though their involvement and role varies based on cultural context. Their capacity and contributions are included in *a priori* planning. They rely on organisational structures, hierarchies and formalised procedures that have existed before the onset of a crisis, comprising the formalised side of CDM.

When unaffiliated volunteers coordinate to address perceived issues, emergence of organisational structure can follow, in the sense of institutions (Berger and Luckmann, 1967). *Emergent groups* form their own identity as a collective and build organisational structures to varying degrees of complexity. They are institutions *in status nascendi* and become more than a simple gathering of unaffiliated volunteers. Emergent groups may be organised with little vertical hierarchy, later developing more formal hierarchies and division of labour. We define emergent groups as a collective of individuals that has formed an organisational structure after the onset of a crisis or disaster, with the purpose of meeting challenges posed by the causal event. As with unaffiliated volunteers, emergent groups operate outside of formalised CDM system and often find no consideration in the planning of response efforts. For an in-depth discussion on the topic of emergent groups, we refer the reader to Drabek and McEntire (2003) as well as Twigg and Mosel (2017).

There are communities within the public whose structures have existed before the onset of the event, but were not established for CDM. These *supporting organisations* take on tasks that fall beyond their usual scope of activity to support relief efforts and keep their internal structures intact while doing so. Whittaker, McLennan and Handmer (2015), as an example for this type of organisation, note Four Wheel Drive clubs organising caravans, transportation and clearing debris in a bushfire event. Our classification closely follows the typology of organisations formulated by Dynes and Quarantelli (1976): formal organisations, supporting organisations and emergent groups correspond to Types I, III and IV, respectively[2]. Transcendence of this typology has been suggested (Drabek and McEntire, 2003; Schmidt et al., 2018), but lies outside the scope of this work.

[2] We have not explicitly included Type II as actor; we consider this to be constituted implicitly through formal organisations managing pre-registered volunteers and expanding in this manner to provide surge capacity.

TAXONOMY OF INTERACTIONS

In the context of CIE, we only consider such interactions as happen between an actor within the organisational system – c.f. (Luhmann, 1995) – of a CDM Organisation and one without. Further, we include those interactions that occur among individual volunteers, emerging organisations and supporting organisations. This excludes the interactions between actors within the organisational system of one or more formal CDM organisations. The taxonomy of interactions thus defined is summarised in Table 2 and described in detail below.

	Category	Functions
A.	Contribution	*Co-creating, Crowdsourcing, Crowdtasking*
B.	Dissemination	*Warning, Preparation & Education*
C.	Experience	*Telling Stories, Sharing Knowledge, Feedback*
D.	Coordination	*Awareness, Orchestration, Intermediation*
E.	Personalisation	*Reception, Personal Mobility, Acknowledgement*

Table 2 Taxonomy of Community Interactions

A. Contribution

Under 'Contribution', we classify interactions to elicit action or information from other actors.

Co-creation

In the context of commerce, (autonomous) co-creation was defined as process where 'individuals or consumer communities produce marketable value in voluntary activities conducted independently of any established organisation, although they may be using platforms provided by such organisations' (Zwass, 2010). The resulting marketable value may be placed in commons, universally shared and accessible to all. The information flow in co-creation is that of all-to-all, whereby every participant eventually has access to the information provided by any other participant. Geiger et al. (2011) classify these interactions as '[i]ntegrative sourcing without remuneration'. When we consider 'marketable value' as being information relevant to crisis management, Zwass' definition represents an approach that is popular in the CDM context. Online social networks, Micro-Blogging platforms and messengers have been successfully used to gather and share relevant situational information (Alexander, 2014; Palen et al., 2009; Vieweg et al., 2010). Support for this activity has previously been considered a worthwhile goal for community infrastructure designed specifically for CDM (Wu et al., 2008). Similarly, many platforms for Volunteer Geographic Information (VGI) are based on co-creation (Haworth, 2016; Meier, 2012). The actors involved in co-creation are primarily unaffiliated volunteers, as both producers and consumers. Formal organisations may also benefit from becoming consumers of such information, if they have the capacity to do so (Alexander, 2014; Haworth, 2016; Simon et al., 2015; Tapia et al., 2011).

Crowdsourcing

This term encompasses a wide variety of approaches, whereby one sourcing actor elicits contributions from a 'crowd' of actors (Geiger et al., 2011). In differentiation to co-creation, the sourcing and contributing actors do not necessarily share peer status in this interaction. Not every actor in the system necessarily has the authority to source for contributions. Similar to co-creation, Wu et al. have also found this type of interaction to be a goal in the design of their Community Response Grid (Wu et al., 2008), though they restrict the applicability of this interaction to incidents that are critical neither in time nor severity. Tapia *et al.* have previously discussed crowdsourcing in the context of citizen science and how this approach can benefit CDM through event detection (Tapia et al., 2014). An example of crowdsourcing in CDM is provided by GDACSmobile, where the submission of relevant information is elicited by enabling a mission space for contribution by any member of the crowd. The manner of contribution is at the discretion of the participant, i.e., which information they submit is decided by their notion of what is important. Information submitted by untrusted volunteers is vetted by a central agency before being re-released to all users (Link et al. 2013, 2015). For an in-depth discussion on sourcing in the CDM context, we refer the reader to Liu's comprehensive crowdsourcing framework (Liu, 2014).

Crowdtasking

To elicit contribution through crowdtasking (Neubauer et al., 2013), a central entity sends a request for specific

information to a selected group of participants, qualified through their skill, experience, or physical location. Crowdtasking is a one-to-many interaction that does not necessarily make contributions available to the crowd. In contrast to crowdsourcing, this interaction usually employs micro-tasking to request specific action and does not allow the submission of information on the crowd's initiative[3]. The crowdtasking concept lends itself to a form of interaction oriented towards the Command and Control paradigm, such as between formal organisations and pre-registered or affiliated volunteers (Auferbauer et al., 2016; Auferbauer and Tellioğlu, 2017). The interplay of the examples we have given for crowdsourcing and crowdtasking in the CDM context has been previously discussed (Middelhoff et al., 2016).

B. Dissemination

The dissemination of information that is relevant to health and safety of citizens in a crisis or disaster represents an exchange between formal organisations and the public as well as unaffiliated and pre-registered volunteers. Whereas in many types of crises and disasters the active involvement of helpers delivers substantial benefits while hardly imposing any limitations on their engagement, there are clearly situations in which their participation should be carefully tailored to the situation on the ground due to concerns for their safety and wellbeing in the context of a dynamically developing situational picture. Technical means of one-to-many (i.e., multicast) or one-to-all (i.e., broadcast) communications are required to inform, warn or alert the potentially affected persons about the prospective or imminent dangers. The quality of such communication is an important factor in building community resilience (Cohen et al., 2017).

Alarming

It is imperative to reach all the potentially affected persons while minimising disturbances to all unaffected persons who should not be bothered with unsolicited information (Collins et al., 2009). Traditionally, societies around the world have been relying on public radio and TV broadcasting and on siren networks in order to warn or alert their citizen about potential public safety-relevant dangers, whereas in recent years SMS, cell broadcast and mobile apps have been added to the portfolio of potential information channels (Gojmerac et al., 2016; Preinerstorfer et al., 2017). These technological advances allow crisis managers to make citizens aware of potential danger in a fine-grained, context-aware manner, alarming only those persons that would potentially be affected, while still increasing the coverage and reach of the dissemination of critical information. Citizens in large urban areas, for example, may be more reliably reached through their phones than via sirens, due to noise pollution and demographic factors (Gojmerac et al., 2016).

Preparation and Education

In the same manner as new ICT allows for a tailored dissemination of critical information in the response and recovery phase of a disaster, so does it also afford crisis managers new ways to prepare and educate citizens in between crises and disasters. The dissemination of information regarding environmental hazards to the local population has been argued to contribute to reducing the vulnerability of both individuals and society, due to an association between a person's risk perception and their disaster preparedness (Helsloot and Ruitenberg, 2004; Miceli et al., 2008). Social networks, multimedia content and web sites provide opportunities to engage citizens, e.g., in public health efforts (Merchant et al., 2011). A wide variety of smartphone applications are already targeted at providing educational material to citizens (Bachmann et al., 2015). Contemporary ICT could be used to further tailor and personalise the disseminated information to the needs and context of the recipient, as well as monitor their perceived and actual level of preparation.

C. Experience

The exchange of personal experience among actors is a category of interaction that serves multiple distinct purposes, depending on recipient and intent of communication.

Sharing Knowledge

The content transmitted during knowledge sharing includes best practices and lessons learned regarding the

[3] We consider this sufficient differentiation between crowdsourcing and crowdtasking. However, the two are undeniably related: crowdtasking has been classified based on Liu's crowdsourcing framework (Liu 2014) by Auferbauer *et al.* (Auferbauer et al. 2016) and further fits the type of crowdsourcing process that Geiger *et al.* defined as 'selective sourcing without crowd assessment' (Geiger et al. 2011).

originating actor's past activity in their respective roles and fosters the collaborative learning of practically relevant knowledge, pertaining to disaster management processes themselves. The information flow in this activity is considered many-to-many; shared knowledge is accessible to all participants of the information system. Supporting this function for emergent groups and unaffiliated volunteers may require different approaches than knowledge management in formal organisations. Due to the high volatility of emergent groups, Majchrzak et al. (2007) suggest that a Transactive Memory System for such entities likely consists of links between tasks that are required and the skills needed to perform these tasks, rather the currently supported links between person and expertise. As the formation of a knowledge base and sharing mechanisms is a normal social process during institutionalisation, it will be necessary to determine the viability of ICT support during the different phases of formation.

Telling Stories

Storytelling is an emotional way of sharing knowledge and creating interpersonal social reality. People connect to common narratives by talking about episodes through the filter of their socialisation. The psychosocial component to cope with distress is important, considering that volunteers are prone to higher mental health impact after volunteering in disasters (Thormar et al., 2010). The content of information exchange shifts, from purely practical subject matter, to experiences that have been stressful for the participant or accounts of their current situation. Participants in our interviews during MEDIATOR have stated that such exchange gives them the feeling of not being alone in their efforts, that their activity is not futile. One participant told us how regular exchange regarding their group's activity has become 'a form of self-help'. Representatives of formal organisations in our group discussions have shown awareness of the importance of this function. They report having established dedicated (digital) points of contact where volunteers can submit accounts of their experiences, and that this feature has found heavy use. Telling stories can either be done via many-to-many interactions, e.g., via a public forum (digital or physical), or in the form of many-to-one submissions of accounts to one actor. Said actor may then selectively disseminate stories they receive to the public.

Feedback

Giving feedback is a one-to-one information exchange, where an individual volunteer submits an account of their experience to a formal organisation. This is intended to either provide emotional relief (regarding an experience that occupies the mind of the volunteer), or to improve the work of the formal organisation (as perceived by the sender). It is differentiated from knowledge sharing and telling stories by being targeted at one specific actor and the subject matter being not necessarily applicable or relevant to actors not involved in the exchange.

D. Coordination

Coordination has been defined as 'the act of managing interdependencies between activities performed to achieve a goal' (Malone and Crowston, 1990) and interpreted as the arrangement of tasks for cooperation through organisation of activity that prevents loss of communication and efforts (Fuks et al., 2008). Solutions for coordination aim to facilitate that actions are planned and conducted in such a way that they utilise the synergies between them and avoid redundant activities in the pursuit of a common purpose.

Awareness

It has been accepted for more than two decades that awareness of participants' activities is critical to cooperation, as far as computational support is concerned (Dourish and Bellotti, 1992). In the context of CDM, that means awareness regarding relief activities of other helpers, capabilities of actors (such as time to deploy, number of personnel and available equipment) and their know-how as well as their organisational structure (so far as it is relevant to coordination). This function becomes especially important when considering interactions between emergent groups and formal organisations: due to the volatile nature of emerging structures, it is difficult for other actors to keep track of their formation and establish contact with the right liaison. During group discussions in project MEDIATOR, formal organisations have reported difficulties when trying to establish communication with emergent organisations, because they were not aware of qualified[4] points of contact. Further, we found that formal organisations would appreciate more awareness regarding the presence and activity of individual, unaffiliated and pre-registered volunteers, to prevent them from overworking

[4] Qualified, in this case, does not necessarily mean that the liaison is in charge or speaks for all the group, but they need to have enough internal standing to act on information. This is particularly true for groups with less vertical hierarchies.

themselves and burning out; volunteers were reported to do shifts that sometimes span multiple days. Considering this, we feel that ICT could contribute through e.g. the concept of awareness by shared feedback: the ability to passively monitor other's action, through continuous and automated status updates, allows the tailoring of one's own contribution and elicits response (Dourish and Bellotti, 1992).

Orchestration

Actors that 'understand' each other, in vocabulary and manner of organisation, can use the same communication channels to work towards a common goal and coordinate *ad hoc*. Orchestration has been investigated as happening between unaffiliated volunteers, resulting in emergent groups. Starbird and Palen (2013), for example, have reported on the work of the initiative 'Humanity Road', consisting of digital volunteers, which was orchestrated to support relief efforts by information processing. This initial orchestration has resulted in an organisational structure with formalised activity and processes. Another example of orchestration has been noted by Kaufhold and Reuter (2016) when they discussed the role of a 'moderator', filled by unaffiliated volunteers, who used social media to mediate supply and demand and to organise other volunteers. They further remark that coordination with formal organisations, in contrast, did not work through social media, which suggests a need for intermediation (see below). For a more in-depth investigation into orchestration, we refer to the publication of Liao et al. (2016).

We would remark that the endeavour of providing a specialised ICT solution for orchestration in CDM likely yields a questionable ratio of benefit to effort when unaffiliated volunteers are involved. In our current research on project MEDIATOR, we found that volunteers can well organise mature organisational structures for orchestration of work within large groups, without the help of specialised ICT solutions. Contemporary online social networks and messengers are sufficient for this purpose and indeed are preferred due to their familiarity. Such observation is in line with works that have reported on volunteer's creative appropriation of technology (Starbird and Palen, 2013; Voida et al., 2015) and social media being well suited for the purpose of volunteer collaboration in disaster response (Waldman and Kaminska, 2015).

Intermediation

Intermediation focuses on bridging the gaps between actors that do not share common communication channels, vocabulary or organisational structure - i.e., cases where interoperability is low. It is not so much the task of coordinating actors in their cooperation towards a certain goal. Rather, intermediation aims at establishing a common ground that makes coordination and cooperation viable in the first place. Such intermediation can contribute specifically to the relation and interaction between unaffiliated volunteers, emergent groups, supporting organisations and formal organisations - actors who follow different organisational structures and are likely diverse regarding their regular activity outside of crisis or disaster situations. Research on a platform to match reports of displaced and found pets in the aftermath of a disaster (Barrenechea et al., 2015) is one example of intermediation through ICT. By providing an appropriate data structure and pulling data from social media into the platform, information is made more accessible to formal organisations (shelters) and exchange is facilitated.

In intermediation, social media channels alone appear to be of limited applicability. While they work well as tools for volunteers to orchestrate efforts with their peers, formal organisations have as of yet not institutionalised them for two-way communication (Alexander, 2014; Simon et al., 2015; Tapia and Moore, 2014). An approach to intermediation that is not primarily technological in nature is postulated by Zettl et al. (2017), who discuss the role of emergent organisations as intermediaries between spontaneous volunteers and emergency organisation.

E. Personalisation

The transitory and self-motivated involvement of citizens (Hustinx and Lammertyn, 2003) requires affordance of greater mobility, regarding the manner of participation.

Reception

Receiving (convergent) helpers is an interaction between formal organisations and unaffiliated volunteers. Due to the problems posed by convergence of people and goods (auf der Heide, 2003; Whittaker et al., 2015), unaffiliated volunteers may come to be seen as a complication, rather than a potential asset (Rogstadius and Teixeira, 2013; Skar et al., 2016). To mitigate this, solutions are required that support formal organisations in the reception of unaffiliated volunteers, while at the same time providing these helpers with information and

guidance. Arriving volunteers will be looking for information on the local situation and where to best apply their efforts. Formal organisations need to register arriving unaffiliated volunteers, to file their skills, capabilities and contact data, as well as to fulfil possible legal obligations. The On-Site Operations Coordination Centre by the United Nations Office for the Coordination of Humanitarian Affairs or the Volunteer Reception Center of the US Federal Emergency Management Agency address the reception of incoming helpers (relief organisations and volunteers, respectively). There have been no investigations into the viability of a digitalisation of this interaction, though the development of such a virtual reception centre could prove helpful (Waldman and Kaminska, 2015).

Personal Mobility

Considering the transitory activity of unaffiliated and pre-registered volunteers, we see an opportunity for ICT to contribute by providing digital identification of helpers' skills, know-how and experience. This function offers a transfer of information from individual, pre-registered or affiliated volunteers towards multiple formal organisations with the goal of quickly signing up for relief activities via an established volunteer identity. Using the concept of cultural capital according to Bourdieu (1986), this means a symbolical representation of embodied cultural capital (of experience and know-how in CDM), potentially transferring it to an institutionalised state.

From an organisational perspective, this means the establishment of a meta-organisation that issues verification of volunteer data. From a technological perspective, such an infrastructure will require a data format and storage option for volunteer data and experience that offers high usability to the volunteer on one hand and meets the standards of formal CDM organisations on the other. We are currently not aware of any such format being widely accepted in CDM. A digital persona of the volunteer could be established at the initial registration (during reception, see above) and stored locally on volunteers' smart devices. From that point, it would be available to returning volunteers as rapid form of 'checking in,' acting as identification and verification. However, the establishment of a persistent digital identity immanently brings with it issues regarding privacy and social impact, potentially leading to discriminative treatment of volunteers based on their past activities.

Acknowledgement

Acknowledging volunteers for their activity stands to reason as being a motivating factor in their engagement – c.f. (Liao et al., 2016). This may be achieved through acknowledgement and showing appreciation (Kriplean et al., 2008), highlighting the importance of a task for common goals (Zhu et al., 2012) or the impact it has on relief efforts (Voida et al., 2015). Our findings from group discussions with formal organisations show that they would appreciate a way to say, 'thank you' to volunteers, while interviews with members of volunteer groups suggest they draw motivation from acknowledgement by peers and formal organisations. Technological support for this interaction has not been extensively addressed. Providing a persistent digital persona for volunteers (see above) could enable such feedback and credit for the contributions of pre-registered and affiliated volunteers.

DISCUSSION

Methodological Considerations in Taxonomy

As Nickerson et al. (2013) have pointed out, the development of taxonomies for information systems has mainly followed an *ad hoc* approach, relying on the researchers' intuition for classification. We must count our present work among them. The taxonomy proposed herein, the dimensions and characteristics it uses for differentiation, have grown over the course of several research projects, instead of being established through a formalised methodology. Further, our classification of actors and interactions could be likened to a typology, based on sociological assumptions regarding volunteers and societal factors, rather than a taxonomy (Smith, 2002). However, Nickerson and colleagues also argue that 'a taxonomy is useful if others use it' and when it allows for observations that were not possible before. Our present work is intended to serve as basis for discussion and guidance – if it serves this purpose, which we are convinced it will, then it offers utility. Nevertheless, we aim for a formal taxonomy development approach in future work on this taxonomy.

On the Classification of Actors

In our taxonomy of actors, we have used as differentiating factor their socialisation in the field of CDM, internalised in the form of long-lasting dispositions. This differentiation is not discrete. Rather, it is a continuum along the axis of the internalisation of the norms, values and social behaviours in CDM. This represents the

degree to which a person's perception, thought and deed are shaped and changed through identification with the field. Such classification draws inspiration from what Bourdieu has termed '*habitus*' – the key between individual behaviour and the social structure of a field, formed through learning processes specific to the field (Kieserling, 2008). Also from Bourdieu (1983) comes the concept of cultural capital, which, in its embodied form ('*Inkorporiertes Kulturkapital*'), becomes part of a person and thus habitus. When we say that socialisation in CDM is used as the distinguishing attribute, we refer to the actor's embodied cultural capital in this field: their attained and incorporated knowledge regarding such things as, e.g., nomenclature, organisational structure, forms of cooperation or processes being followed.

Conversely, the differentiation between affiliated supporters and affiliated decision-makers could arguable be made based on *institutionalised cultural capital* instead, such as, e.g., titles, rank or certifications, which can be used societally to determine the cultural competencies of a person. Such symbols are canonical and confer a different kind of cultural capital than the embodied form, i.e. 'the capital of the auto-didact, which may be called into question at any time' (Bourdieu, 1986). The circumstance that these symbols likely hold more value in a hierarchical context (such as most formal CDM organisations) than they would in emergent groups, where social capital potentially plays a larger role, suggests segmentation of the field (Anheier et al., 1995). A more thorough examination of actors in CIE through the lens of Bourdieu's theories appears an intriguing prospect for future work.

Lack of Multi-Dimensional Representation

Any eventual taxonomy of CIE that aims to model a substantial part of interactions will necessarily be of multi-dimensional character; for classifying both actors and interactions. We expect distinctions to be added on multiple levels to the one-dimensional classifications in this paper. Given that the present work follows from research that is empirically disposed, space and time would be obvious candidates in the light of transcendental idealism. A spatial dimension may be introduced by differentiating between 'on-site' and 'virtual' actors (also: 'online' or 'digital'); such as in the case of volunteers (Kaufhold and Reuter, 2016; Schmidt et al., 2018; Starbird and Palen, 2013). Introduction of a temporal dimension may be based on the phases of the disaster management cycle; to differentiate in more detail the interactions we have presented. Further, our classification of interactions is based on the primary intent under which actors use ICT for interaction. It does not consider latent social functions of interactions; such as building trust (Hughes and Tapia, 2015), persuading actors (Vineyard et al., 2012) or building new structures (Liao et al., 2016).

Global Applicability

From a constructivist point of view, we consider it important to note the cultural preconceptions that influence this work. Related literature we have considered is primarily published in Anglo-American and Western European venues and written in English, which is relevant both due to the cultural context from which data was drawn and when considering that the language being used itself exerts an influence. Cultural differences will, without doubt, affect the applicability of our taxonomies and any eventual technological framework based on them.

CONCLUSION

There currently exists no comprehensive, systematic description, classification or taxonomy of Community Interaction and Engagement (or any otherwise named domain with a comparable definition). Because taxonomies are integral to systems engineering and provide the foundation for technological advances by structuring our knowledge of a field, we address this gap to facilitate future development of ICT. As the primary contribution of this work, we have provided two taxonomies for the context of CIE: one that classifies its actors and a second that classifies the interactions between them. They shall provide the reader with an improved understanding and overview of the different types of interaction in CIE and offer an outline for potential contributions through ICT.

ACKNOWLEDGEMENTS

This work was funded by the Österreichische Forschungsförderungsgesellschaft mbH under the Research Partnership Programme: 'The Industrial PhD Programme 2015' - Grant No. 851629

REFERENCES

Alexander, D. E. (2014) Social Media in Disaster Risk Reduction and Crisis Management, *Science and*

Engineering Ethics, 20(3), 717–733.

Anheier, H. K., Gerhards, J., and Romo, F. P. (1995) Forms of Capital and Social Structure in Cultural Fields: Examining Bourdieu's Social Topography, *American Journal of Sociology*, 100, 4, 859–903.

auf der Heide, E. (2003) Convergence behavior in disasters, *Annals of Emergency Medicine*, 41, 4, 463–466.

Auferbauer, D., Ganhör, R., Tellioğlu, H., and Pielorz, J. (2016) Crowdtasking: Field Study on a Crowdsourcing Solution for Practitioners in Crisis Management, *Proceedings of the ISCRAM 2016 Conference*, Rio de Janeiro.

Auferbauer, D., and Tellioğlu, H. (2017) Centralized Crowdsourcing in Disaster Management, *Proceedings of the 8th International Conference on Communities and Technologies - C&T '17*, ACM Press, New York, New York, USA, 173–182.

Bachmann, D. J., Jamison, N. K., Martin, A., Delgado, J., and Kman, N. E. (2015) Emergency preparedness and disaster response: There's an app for that, *Prehospital and Disaster Medicine*, 30, 5, 486–490.

Barrenechea, M., Anderson, K. M., Palen, L., and White, J. (2015) Engineering crowdwork for disaster events: The human-centered development of a lost-and-found tasking environment, *Proceedings of the Annual Hawaii International Conference on System Sciences*, 182–191.

Barsky, L. E., Trainor, J. E., Torres, M. R., and Aguirre, B. E. (2007) Managing volunteers: FEMA's Urban Search and Rescue programme and interactions with unaffiliated responders in disaster response, *Disasters*, 31, 4, 495–507.

Berger, P. L., and Luckmann, T. (1967) The Social Construction of Reality, *The Modern Language Journal*, 51, 5, 307.

Bourdieu, P. (1983) Ökonomisches Kapital, kulturelles Kapital, soziales Kapital, *Soziale Ungleichheiten*, 183–198.

Bourdieu, P. (1986) The Forms of Capital, *Readings in Economic Sociology*, Blackwell Publishers Ltd, Oxford, UK, 280–291.

Cohen, O., Goldberg, A., Lahad, M., and Aharonson-Daniel, L. (2017) Building resilience: The relationship between information provided by municipal authorities during emergency situations and community resilience, *Technological Forecasting and Social Change*, 121, 119–125.

Collins, A., Maunder, N., McNabb, M., Moorhead, A., and Aalst, M. van. (2009) *World Disasters Report 2009: Focus on Early Warning, Early Action*. *Disasters*, (L. Knight, ed.).

Curnin, S., and Owen, C. (2013) A typology to facilitate multi-agency coordination, *Proceedings of the 10th International ISCRAM Conference*, Baden Baden, Germany, 115–119.

Dourish, P., and Bellotti, V. (1992) Awareness and coordination in shared workspaces, *Proceedings of the 1992 ACM conference on Computer-supported cooperative work - CSCW '92*, ACM Press, New York, New York, USA, 107–114.

Drabek, T. E., and McEntire, D. A. (2003) Emergent phenomena and the sociology of disaster: lessons, trends and opportunities from the research literature, *Disaster Prevention and Management: An International Journal*, 12, 2, 97–112.

Dynes, R. R. (1994) Community Emergency Planning: False Assumption and Inappropriate Analogies, *International Journal of Mass Emergencies and Disasters*, 12, 2, 141–158.

Dynes, R. R., and Quarantelli, E. L. (1976) *Organizational communications and decision making in crises*. Columbus.

Eide, A. W., Haugstveit, I. M., and Borén, M. (2013) Inter-organizational Collaboration Structures during Emergency Response : A Case Study, *Proceedings of the 10th International ISCRAM Conference*, Baden-Baden, Germany, 94–104.

Fuks, H., Raposo, A., Gerosa, M. A., Pimental, M., and Lucena, C. J. P. (2008) The 3C Collaboration Model, *Encyclopedia of E-Collaboration*, IGI Global, 637–644.

Geiger, D., Seedorf, S., Nickerson, R., and Schader, M. (2011) Managing the Crowd: Towards a Taxonomy of Crowdsourcing Processes, *Proceedings of the Seventeenth Americas Conference on Information Systems*.

Gojmerac, I., Preinerstorfer, A., Ruggenthaler, C., Schuster, C., Almer, A., Stocker, R., and Heussler, V. (2016) Public warning and alert system for Austria, *2016 3rd International Conference on Information and Communication Technologies for Disaster Management - ICT-DM'16*, Vienna, Austria.

Harris, M., Shaw, D., Scully, J., Smith, C. M., and Hieke, G. (2017) The Involvement/Exclusion Paradox of Spontaneous Volunteering, *Nonprofit and Voluntary Sector Quarterly*, 46, 2, 352–371.

Haworth, B. (2016) Emergency management perspectives on volunteered geographic information: Opportunities, challenges and change, *Computers, Environment and Urban Systems*, Elsevier Ltd, 57, 189–198.

Helsloot, I., and Ruitenberg, A. (2004) Citizen response to disasters: A survey of literature and some practical implications, *Journal of Contingencies and Crisis Management*, 12, 3, 98–111.

Hughes, A. L., and Tapia, A. H. (2015) Social Media in Crisis: When Professional Responders Meet Digital Volunteers, *Journal of Homeland Security and Emergency Management*, 12, 3.

Hustinx, L., and Lammertyn, F. (2003) Collective and Reflexive Styles of Volunteering: A Sociological Modernization Perspective, *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations*, 14, 2, 167–187.

Kaufhold, M.-A., and Reuter, C. (2016) The Self-Organization of Digital Volunteers across Social Media: The Case of the 2013 European Floods in Germany, *Journal of Homeland Security and Emergency Management*, 13, 1, 137–166.

Kieserling, A. (2008) Felder und Klassen: Pierre Bourdieus Theorie der modernen Gesellschaft, *Zeitschrift für Soziologie*, 37, 1, 3–24.

Kriplean, T., Beschastnikh, I., and McDonald, D. W. (2008) Articulations of wikiwork, *Proceedings of the ACM 2008 conference on Computer supported cooperative work - CSCW '08*, ACM Press, New York, USA, 47-56.

Liao, Q. V., Bellotti, V., and Youngblood, M. (2016) Improvising Harmony, *Proceedings of the 19th International Conference on Supporting Group Work - GROUP '16*, ACM Press, New York, USA, 159–169.

Link, D., Hellingrath, B., and Groeve, T. De. (2013) Twitter Integration and Content Moderation in GDACSmobile, *Proceedings of the 10th International ISCRAM Conference*, Baden-Baden, Germany, 67–71.

Link, D., Widera, A., Hellingrath, B., de Groeve, T., Eidimtaite, G., and Limbu, M. K. (2015) GDACSmobile-An IT Tool Supporting Assessments for Humanitarian Logistics, *The International Emergency Management Society (TIEMS) 2015 Annual Conference,* Rome, Italy.

Liu, S. B. (2014) Crisis Crowdsourcing Framework: Designing Strategic Configurations of Crowdsourcing for the Emergency Management Domain, *Computer Supported Cooperative Work (CSCW)*, 23, 389–443.

Liu, S., Brewster, C., and Shaw, D. (2013) Ontologies for Crisis Management: A Review of State of the Art in Ontology Design and Usability, *Proceedings of the 10th International ISCRAM Conference*, 349–359.

Luhmann, N. (1995). *Social systems*. Stanford University Press.

Majchrzak, A., Jarvenpaa, S. L., and Hollingshead, A. B. (2007) Coordinating Expertise Among Emergent Groups Responding to Disasters, *Organization Science*, 18, 1, 147–161.

Malone, T. W., and Crowston, K. (1990) What is coordination theory and how can it help design cooperative work systems?, *Proceedings of the 1990 ACM conference on Computer-supported cooperative work - CSCW '90*, ACM Press, New York, USA, 357–370.

Meier, P. (2012) Crisis Mapping in Action: How Open Source Software and Global Volunteer Networks Are Changing the World, One Map at a Time, *Journal of Map & Geography Libraries*, 8, 2, 89–100.

Merchant, R. M., Elmer, S., and Lurie, N. (2011) Integrating Social Media into Emergency-Preparedness Efforts, *New England Journal of Medicine*, 365, 4, 289–291.

Miceli, R., Sotgiu, I., and Settanni, M. (2008) Disaster preparedness and perception of flood risk: A study in an alpine valley in Italy." *Journal of Environmental Psychology*, 28, 2, 164–173.

Middelhoff, M., Widera, A., van den Berg, R. P., Hellingrath, B., Auferbauer, D., Havlik, D., and Pielorz, J. (2016) Crowdsourcing and crowdtasking in crisis management: Lessons learned from a field experiment simulating a flooding in the city of the Hague, *2016 3rd International Conference on Information and Communication Technologies for Disaster Management - ICT-DM'16*, Vienna, Austria.

Neubauer, G., Nowak, A., Jager, B., Kloyber, C., Flachberger, C., Foitik, G., and Schimak, G. (2013) Crowdtasking – A New Concept for Volunteer Management in Disaster Relief, *Environmental Software Systems. Fostering Information Sharing*, IFIP Advances in Information and Communication Technology, Springer Berlin Heidelberg, 345–356.

Nickerson, R. C., Varshney, U., and Muntermann, J. (2013) A method for taxonomy development and its application in information systems, *European Journal of Information Systems*, 22 ,3, 336–359.

Palen, L., and Liu, S. B. (2007) Citizen communications in crisis, *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '07*, ACM Press, New York, USA, 727–736.

Palen, L., Vieweg, S., Liu, S. B., and Hughes, A. L. (2009) Crisis in a Networked World: Features of Computer-Mediated Communication in the April 16, 2007, Virginia Tech Event, *Social Science Computer Review*, 27, 4, 467–480.

Preinerstorfer, A., Egly, M., Gojmerac, I., Hochwarter, C., Schuster, C., and Stocker, R. (2017) Requirements for the next generation Public Warning and Alert System for Austria, *2017 14th International Conference on Telecommunications (ConTEL)*, IEEE, 115–122.

Prince, S. H. (1920) Catastrophe and social change - based upon a sociological study of the Halifax disaster, Columbia University, New York, NY, USA.

Rogstadius, J., and Teixeira, C. (2013) An Introduction for System Developers to Volunteer Roles in Crisis Response and Recovery, *Proceedings of the 10th International ISCRAM Conference*, Baden-Baden, Germany, 874–883.

Schmidt, A., Wolbers, J., Ferguson, J., and Boersma, K. (2018) Are you Ready2Help? Conceptualizing the management of online and onsite volunteer convergence, *Journal of Contingencies and Crisis Management*, 26, 3, 338–349.

Simon, T., Goldberg, A., and Adini, B. (2015) Socializing in emergencies - a review of the use of social media in emergency situations, *International Journal of Information Management*, Elsevier Ltd, 35, 5, 609–619.

Skar, M., Sydnes, M., and Sydnes, A. K. (2016) Integrating unorganized volunteers in emergency response management, *International Journal of Emergency Services*, 5, 1, 52–65.

Smith, K. B. (2002) Typologies, Taxonomies, and the Benefits of Policy Classification, *Policy Studies Journal*, 30, 3, 379–395.

Starbird, K., and Palen, L. (2013) Working and sustaining the virtual 'Disaster Desk', *Proceedings of the 2013 Conference on Computer Supported Cooperative Work*, ACM Press, New York, USA, 491–502.

Tapia, A. H., Bajpai, K., Jansen, B. J., and Yen, J. (2011) Seeking the Trustworthy Tweet : Can Microblogged Data Fit the Information Needs of Disaster Response and Humanitarian Relief Organizations, *Proceedings of the 8th International ISCRAM Conference*, Lisbon, Portugal.

Tapia, A. H., LaLone, N., MacDonald, E., Priedhorsky, R., and Hall, M. (2014) Crowdsourcing rare events: Using curiosity to draw participants into science and early warning systems, *Proceedings of the 11th International ISCRAM Conference*, Pennsylvania, USA, 135–144.

Tapia, A. H., and Moore, K. (2014) Good Enough is Good Enough: Overcoming Disaster Response Organizations' Slow Social Media Data Adoption, *Computer Supported Cooperative Work (CSCW)*, 23, 483–512.

Thormar, S. B., Gersons, B. P. R., Juen, B., Marschang, A., Djakababa, M. N., and Olff, M. (2010) The Mental Health Impact of Volunteering in a Disaster Setting, *The Journal of Nervous and Mental Disease*, 198, 8, 529–538.

Twigg, J., and Mosel, I. (2017) Emergent groups and spontaneous volunteers in urban disaster response, *Environment and Urbanization*, 29, 2, 443–458.

Vieweg, S., Hughes, A. L., Starbird, K., and Palen, L. (2010) Microblogging during two natural hazards events, *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, ACM Press, New York, USA.

Vineyard, C. M., Lakkaraju, K., Collard, J., and Verzi, S. J. (2012) The Impact of Attitude Resolve on Population Wide Attitude Change, *Social Computing, Behavioral - Cultural Modeling and Prediction*, Springer Berlin Heidelberg, Berlin, Heidelberg, 322–330.

Voida, A., Yao, Z., and Korn, M. (2015) (Infra)structures of Volunteering, *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing - CSCW '15*, ACM Press, New York, USA, 1704–1716.

Waldman, S., and Kaminska, K. (2015). *Connecting emergency management organizations with digitally enabled emergent volunteering Literature review and best practices*, Defence Research and Development Canada – Centre for Security Science

Whittaker, J., McLennan, B., and Handmer, J. (2015) A review of informal volunteerism in emergencies and disasters: Definition, opportunities and challenges, *International Journal of Disaster Risk Reduction*, 13, 358–368.

Wu, P. F., Qu, Y., Preece, J., Fleischmann, K., Golbeck, J., Jaeger, P., and Shneiderman, B. (2008) Community response grid (CRG) for a university campus: Design requirements and implications, *Proceedings of the 5th International ISCRAM Conference*, 34–43.

Zettl, V., Ludwig, T., Kotthaus, C., and Skudelny, S. (2017) Embedding unaffiliated volunteers in crisis management systems: Deploying and supporting the concept of intermediary organizations, *Proceedings of the 14th ISCRAM Conference*, Albi, France, 421–31.

Zhu, H., Kraut, R., and Kittur, A. (2012) Organizing without formal organization, *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work - CSCW '12*, 935--945.

Zwass, V. (2010) Co-Creation: Toward a Taxonomy and an Integrated Research Perspective, *International Journal of Electronic Commerce*, 15, 1, 11–48.

Identifying functions for smartphone based applications in volunteer emergency response

Elina Ramsell
Linköping University
elina.ramsell@liu.se

Tobias Andersson Granberg
Linköping University
tobias.andersson.granberg@liu.se

Sofie Pilemalm
Linköping University
sofie.pilemalm@liu.se

ABSTRACT

Emergency response organisations struggle with resource constraints and thereby faces challenges in providing high-quality public services. Utilising voluntary first responders is one way to address these challenges. There are different types of volunteers who can help at an emergency site, e.g. citizen volunteers or voluntary professionals from other occupations. To successfully engage with and utilise these resources, adequate information and communication technology (ICT) is necessary. In this meta-study, combining and further exploring two previous studies, the aim is to identify, analyse and evaluate suitable functions for smartphone applications that can be used to dispatch and support volunteers. The results show that the functions can be divided into essential ones that are necessary for the response to work at all, and others that might contribute to a more effective response. The study also shows that the same functions can be used for different volunteer groups.

Keywords

Voluntary emergency response, ICT, smartphone application, end users, co-production.

INTRODUCTION

In many countries, high public demand and decreased budgets make it difficult to maintain proper service levels for emergency response. In rural areas, professional first responders are supposed to serve geographically large jurisdictions, while in urban areas few responders often serve large populations. When distances become longer, and available rescue personnel are scarce, nearby volunteers might be dispatched to emergencies to provide assistance before professional responders arrive, potentially saving lives and mitigating damage. Previous research has highlighted the need for more studies concerning onsite volunteers (Schmidt et al., 2018) and pre-planned and long-term collaborations with professional emergency response (Diaz et al., 2016; Johansson et al., 2018).

Two emerging types of pre-planned and onsite volunteers as first responders are citizen volunteers and semi-professional volunteers, who respond to local accidents or medical incidents in collaboration with the professional emergency services (police, fire, emergency medical services). Citizen volunteers can be neighbours helping each other in their village or residential area. Thus, they have no formal organisational affiliation (Jaeger et al., 2007; Linders, 2012; Venema et al., 2010; Whittaker et al., 2015). Voluntary semi-professionals on the other hand are employed, or paid, by some level of government (typically local, e.g. municipal) to take on additional tasks in emergency response (SOU, 2018). Thus, they have their regular full-time employment and add on the new responsibility as a first responder (Sund and Jaldell, 2018; Venema et al., 2010). Semi-professionals can be seen as a kind of volunteers, just like citizen volunteers. Even though they perform their new tasks as part of their employment, in most cases it is not mandatory to accept the new duties and it is always up to themselves if they want to respond to an emergency or not. These two emerging types of

volunteering can be viewed as co-production of public services (Alford, 2014; Ostrom, 2016). Volunteering have also been referred to as "do-it-yourself government" as an emerging culture within public services (Linders, 2012; Venema et al., 2010). Although co-production seldom focuses on the information and communication technology (ICT) artefact, current public-sector trends all have modern ICT as an enabler. However, the existing infrastructure for emergency dispatch (e.g. radio) is often not convenient or available to voluntary first responders (due to e.g. organisational hindrances and legal obstacles) (Ramsell et al., 2017). Therefore, new ICT solutions become necessary in order to coordinate their emergency response work with professional first responders.

Many initiatives utilising the new resources have opted to use smartphone-based solutions (e.g. Gomez and Murray Turof, 2007; Ringh et al., 2011). However, studies have shown that developing and using these includes a number of unsolved challenges, e.g. identifying suitable functions based on end-user needs (Havlik et al., 2016; Roberts et al., 2014; Schönböck et al., 2016). This perceived knowledge gap is addressed in this study. In addition, earlier studies (Mojir et al., 2018; Ramsell et al., 2017) indicate that basic needs for such resources, such as training and equipment, are often similar for different voluntary groups, but research to establish whether this is also true for the specific ICT artefact is needed.

Study Aim

The aim of this study is to:

- Identify and evaluate suitable functions of an ICT artefact in the form of a smartphone application, based on end-user involvement (the volunteers).
- Explore whether the same ICT functions, can be used for different volunteer groups.

The study is a meta-analysis, built on two previous case studies analysing and identifying both general needs and ICT needs of two different volunteer groups: citizen volunteers and semi-professional volunteers. Both take place in the context of Swedish emergency response. However, since many basic tasks in first response are similar at an international scale, the results are also discussed in a wider emergency response context. For instance, the existing research on specific platforms and applications for volunteers in disaster management (e.g. de Lanerolle et al., 2010; Schmidt et al., 2018) may benefit from this study's contributions.

THEORETICHAL CONTEXT: CO-PRODUCTION AND USING VOLUNTEERS AS FIRST RESPONDERS

Voluntary engagement that is informal yet conducted in collaboration with professional response is described using different terms in the literature. For instance, Whittaker et al. (2015) highlight "spontaneous organisation volunteers", Diaz et al. (2016) use the concept of "citizens as agents", and St. Denis and Hughes (2018) report on an online application used with "trusted volunteers" of emergent community groups. Thus, to define the two voluntary groups in this study – citizen volunteers and semi-professional volunteers – we use a broad definition: "volunteerism refers to the activities of people who work outside of formal emergency and disaster management arrangements to help others who are at risk or are affected by emergencies and disasters" (Whittaker et al., 2015:361).

At a societal level, it is possible to see a shift in public service delivery, and emergency response specifically, where communities, citizens and other professions are increasingly involved in first response. Here, the exchange of resources, non-hierarchical patterns and social relations are some of the keywords among different types of actors united in the common endeavour of providing more effective and flexible public services (Agranoff and McGuire, 2010; Börzel, 1998). These kinds of collaborations are usually described by network concepts such as collective action (e.g. Carlsson, 2000), collaborative networks (e.g. Agranoff, 2006) and network governance (e.g. Loukis, 2016). A common denominator is the necessity of ICT in the networks, whereby ICT "helps connect various actors to the network, build relationships between them, […] and manage[s] and sustain[s] the networks themselves" (Janowski et al., 2012:52).

Building on the network context, the concept of ***co-production*** can be used to more specifically describe different actors' involvement in public-service delivery, e.g. volunteers. With digitalisation, the possibilities to co-produce have increased (Linders, 2012). For instance, nowadays almost everybody has a smartphone that can be used for advanced information exchange and coordination. According to the definition, co-production is "the process through which inputs used to produce a good or service are contributed by individuals who are not 'in' the same organization" (Ostrom 1996: 1073). Alford (2014) mentions one example of co-production in which a Fire and Emergency Services organisation expanded the role of residents to include performing different preventive tasks aimed at protecting "life, property and the environment" (Alford, 2014:302).

In this study, ***ICT-facilitated co-production*** is used as a concept to describe volunteers' involvement in emergency response. Specifically, two different types of voluntary co-production initiatives are in focus. ***Semi-professional volunteers*** refers to persons who, as part of their professional work, volunteer to act as first responders. ***Citizen volunteers*** refers to citizens taking over certain tasks from the authorities for themselves and their co-citizens, creating a "do-it-yourself government" (Brandsen et al., 2018; Diaz et al., 2016; Linders, 2012). While volunteer engagement has been studied using various network perspectives from different research disciplines – including co-production – the perspectives have in common that they seldom focus on the ICT artefacts, but rather on politics, policies, values, economic and welfare aspects. (Agranoff, 2006; Carlsson, 2000; Janowski et al., 2012; Loukis, 2016). Regardless, the technology is a prerequisite for the phenomenon in the first place; if the ICT does not work adequately, volunteers cannot be dispatched to act as first responders.

Earlier research emphasizing the ICT artefact for volunteers in emergency and disaster response often focus directly on the technical solution and general evaluations of the solution, while the process by which it is reached is seldom explored in detail (e.g. Ferguson et al., 2016; Ringh et al., 2011). We have not managed to find earlier research where the users' perception is central, what their actual needs and requirements are. In some studies it is possible to receive information about identified functions even though this is not the core focus of the studies (see Table 1.). Thus, here we believe that our study can make a significant contribution. In order to enrich previous research, it focuses on the ICT artefact in a co-production context, and how it should be realised in order to be useful for various types of volunteers.

Table 1. Functions of ICT solutions (smart phones) for volunteers in disaster and emergency response

Functions	**Earlier studies**							
	Aufer-bauer and Ganhör, 2015	Berg-lund et al., 2018	Gomez and Murray Turof, 2007	Havlik et al., 2016	de Lan-erolle et al., 2010	Meissen et al., 2017	Schmidt et al., 2018	Schön-böck et al., 2016
Registration (app/online)	x					x		x
Personal profiles (skills/competencies)	x			x		x	x	x
Alert through SMS/app	x	x	x	x	x	x	x	x
Information (description of the incident/task)	x	x		x		x		x
Acknowledgement		x				x	x	x
Navigation/map	x	x		x		x	x	x
Bringing equipment								x
Communication possibility/two way communication				x	x			x
Send image, video, audio from incident	x							
Gamification/reward (to foster motivation)								x
Feedback/evaluation		x						x

METHODS

This study is a meta-analysis of two earlier case studies of volunteer engagement in emergency response (Mojir et al., 2018; Ramsell et al., 2017). The former took a broader perspective, encompassing the overall collaborations, including training, equipment, legal issues and also specific needs for ICT, but without a thorough analysis or evaluation of the functions of an ICT solution. Therefore, we now focus on the functions identified and implemented in a prototype smartphone application, and explore it in relation to the two voluntary groups, i.e. the semi-professionals and the citizen volunteers.

Study Context in the Separate Cases

The two previous studies here can be described as exploratory, referring to case studies that explore emerging phenomena (Flyvbjerg, 2006).

Case 1 was the development of the concept of ***semi-professional*** first responders in the municipality of Norrköping (a medium-sized municipality in south-east Sweden). The project ran from 2015 to 2017. The purpose of the project was to identify, analyse and evaluate potential first responders who could support the professional first responders, e.g. by extinguishing small fires or performing first aid. An additional purpose of the project was to identify their needs for training, equipment and ICT support. There was no existing organisation or infrastructure at project start. Therefore, a prototype smartphone application for semi-professional first responders was developed. Four different professional groups were analysed: security guards, home-care personnel, municipal facility service personnel and day personnel at the fire and rescue services (FRS). Finally, day personnel at the FRS were selected as voluntary first responders in the project. The day personnel are not part of the operative response organisation, but work with such aspects as logistics and the procurement of materials, information management, education and inspections.

Case 2 was an emerging collaboration, initialised by the FRS in the rural province of Medelpad which was first studied 2014-2015 and then 2017, where ***citizen volunteers*** were provided with training to enable them to perform first response to accidents and selected emergency medical cases in their own villages, such as fires, traffic accidents, drownings and cardiac arrest. Some volunteers were, or had been, working within the medical or rescue domain, while others had no previous experience. Many of the volunteers were retired, and others worked on farms or in sawmills. The selection criterion to start a voluntary group in a village was that the expected response time for the FRS should be at least 25 minutes. When there was an incident in one of the villages, all volunteers in the village were alerted by an SMS (short message service) on their private mobile phones through the Swedish PSAP (in Sweden this is SOS Alarm, which is responsible for answering the national emergency number 112, and also for dispatching some emergency response resources and coordinating different emergency response organisations). To find a more sophisticated ICT solution for the volunteers, with additional functions, the same prototype smartphone application as in Case 1 was adapted to the citizen volunteers' specific needs.

Data Collection

In both cases, a variety of methods were used to collect data, including semi-structured interviews, focus group interviews and future workshops. Throughout the data collection, end users have been the source of information and have participated actively. More detailed information concerning the data collection in each case is reported in Mojir et al. (2018) and Ramsell et al. (2017).

Prototype Development – a Smartphone Application

Based on the data collection for each case, specific ICT functions for the end users were identified for each voluntary group. To test how these functions could be implemented, and to analyse and evaluate them, a ***prototype smartphone application*** was developed. The reason why we developed a prototype instead of using an already existing application, e.g. Mobile Life Saver, MLS (Ringh et al. 2011) or a commercial application such as Safeland (safeland.se) was to gain a better experimental control for the study. A compilation of identified functions was conducted, and a selection was implemented in the prototype, based on which: a) were considered most important by the volunteers and b) were possible to implement and test.

The prototype are for smartphones running on the Android operating system. The primary function of the application is to be able to receive an alert. When this happens, the application notifies the user with a signal, and a notification on the lock screen and in the notification list. When the user has opened the application, brief information about the incident is presented, and the user can accept (green button) or decline (red button) to go (See Figure 1).

Figure 1. A new alert in the smartphone application

A first prototype was developed in Case 1, but partly based on results and learning outcomes from Case 2, where some user needs had already been collected. After using and testing the application in Case 1, the application was used in Case 2 with some additional functionality based on an additional data collection in the later phase of the study.

Tests of the functions and Evaluation

Four tests were conducted in which the smartphone application was tested by the volunteers/end users. Thereafter, the tested functions were evaluated and discussed by the users, who reflected on which functions seemed satisfying, which could be improved, and possible solutions. Since this study is a meta-analysis, the tests are not identical or designed to be comparable across the two cases, but they all have the overall aim of determining whether the functions fit the end users' needs.

Test 1 was performed over a time-span of two months. Nine potential ***semi-professional*** first responders in Case 1 were equipped with a smartphone with the application installed. Alerts were sent to the participants, who were supposed to indicate, whether they would have been able to accept the assignment, had it been a real case (they were not supposed to go to the incident site). During the test period, an online qualitative questionnaire was available where the participants could give feedback about the test and the application, and suggest new functionality.

Test 2 was performed with two of the ***semi-professional*** first responders from Case 1, who were dispatched to a simulated traffic accident with two injured victims. The responders were placed in their own cars and received the alert on the smartphone application. They went to the accident site and performed first aid until the arrival of the emergency medical services and the FRS. The test was observed and filmed, and was also evaluated in an After-Action-Review (AAR; Myers, 2009) with all participants (semi-professionals, FRS, ambulance services), where the application and its functionality were discussed.

Test 3 was performed with five ***citizen volunteers*** from Case 2 during two days. Before the test, the participants had to download and install the application onto their own Android-based smartphones. During the test, a set of alerts was sent to the participants, who could accept or decline according to their own preference. The aim was for them to become familiar with the application and its functions. About a week after the test, a group interview was held in which the application and its functions were evaluated.

Test 4 was also held with ***citizen volunteers*** from Case 2 and partly as a consequence of the low number of

participants in Test 3, as the requirements of having your own smartphone and being able to install an application were too high for many potential participants. Thus, this test was performed as a workshop with one moderator (researcher and first author of this paper) and with prepared smartphones that the participants could borrow. This resulted in 12 participants who, during the test, received alerts and tested and evaluated the application and its functions.

Meta-analysis

From the collected data, a comparative meta-analysis was conducted. First, we collected all functions which were identified in both cases. Secondly, we went through the functions once again to get a more detailed understanding and to compare them; e.g. if similar or the same functions were identified in both cases, and what differences there were. After this, we grouped the functions in a) all identified functions, b) functions identified in both cases and c) functions only identified in one of the cases. In group a) we also added the volunteers' perception of each function. Then, with help from the grouping, we summed up the analysis of the functions, i.e. which functions the users perceived were most important and if these were the same or not for both volunteer groups. Finally, to generalise the results and put them into context (i.e. co-production), we compared the identified functions with studies from the literature.

RESULTS

The results include the identified functions, as well as user feedback from the tests and evaluations.

Identified ICT Functions

From the two cases, 12 functions were identified by both of the two groups (see Table 2). One additional function, information to the employer (No. 6), was identified by the semi-professionals, but was not applicable to the citizen volunteers (because they have no employer in their role as first responders). In Table 1, the 13 identified functions are ordered according to how they would occur during a mission; with the non-mission-specific check in/check out function (No. 1) at the top, followed by the alert signal (No. 2), and ending with a function for leaving and receiving feedback (No. 13), which occurs after a finished mission. While some of the functions are self-explanatory, additional information is provided for the others below.

The ability to check in and check out (No. 1) is requested by responders who will sometimes not be able to accept a mission for some time (hours, days or weeks), but still want to remain a responder. The ability to see who else accepts an assignment (No. 5) was highly desired by citizen volunteers, while some of semi-professional volunteers stated that it should not matter who else responds; if you get the mission, you should go either way.

Information to the employer that the responder has deviated from normal duties (No. 6) was only relevant for semi-professional volunteers; even though it is possible that a citizen volunteer will leave their ordinary job to go on a first response alert, the responsibility for the regular work tasks left undone would remain with the volunteer. Comparing this to semi-professional volunteers, the responsibility would transfer to the employer, since semi-professionals are doing first response as a task within their current employment contract. By notifying the employer, it is possible to arrange substitutes, or just reschedule the abandoned task for later.

The ability to communicate that a volunteer should abort a mission (No. 8) was originally suggested by professional response personnel in discussion with volunteers, who also thought that this function would be useful. For instance, if volunteers have been dispatched to an incident, and new information indicates that the situation is dangerous (e.g. gunfire or toxic substances), there should exist some quick way of reaching the volunteers to tell them to stop and wait. Another abort signal, but from the volunteer responder side (No. 9), was also deemed useful. It should be possible for a voluntary responder to indicate that the mission will be aborted, if he/she cannot reach the incident site; e.g., due to car problems.

In terms of a checklist for the responders (No. 11), various ways of having the application support the work on site were discussed; for example, having specific written (or audio) instructions for different types of incidents, or connecting it to other existing applications (e.g. first-aid guides).

While it is technically easy to implement communication with professional responders or emergency call operators (No. 12), it is more complicated to determine who should be contacted. One obvious choice is just to add a button that enables a call to the national emergency number 112. Since the PSAP in Sweden is responsible for coordinating different emergency response resources, this makes sense. However, when calling 112, if the closest alarm centre is busy, the call is transferred to another centre, where the operators might not know about the new resources, and time might be lost if the volunteers have to explain their role in the response.

Feedback (No. 13) can be used for different purposes; firstly, when the voluntary responders want to share their experiences in order to facilitate learning and development. Secondly, it can also be used to initiate a dialogue, or request help with dealing with potentially traumatic experiences related to an emergency response.

Table 2. Identified functions by voluntary first responders

No.	Identified functions	by semi-prof. volunteers	by citizen volunteers
1	**Check in/check out**: The possibility to opt out of the role of responder for a limited time	x	x
2	**Loud and unique signal:** It has to be possible to hear an alert at all times, and it should not be mistaken for any other notification	x	x
3	**Information**: A brief description of the incident	x	x
4	**Acknowledgement**: The possibility to accept or decline a mission	x	x
5	**Other voluntary responders**: It is possible to see who else has accepted the mission	x	x
6	**Information to employer**: Automatic information to the employer that the responder has deviated from normal duties	x	Not applicable
7	**Navigation**: A map with the incident site marked, navigational instructions, voice navigation	x	x
8	**Abort**: Information if the mission needs to be aborted, due to a dangerous incident site, or if the responder is no longer needed	x	x
9	**Abort status**: The possibility to indicate that the mission has been aborted	x	x
10	**Arrival status**: The possibility to indicate arrival at the incident site	x	x
11	**Checklist**: Information supporting practical response, e.g. how to act in specific accidents	x	x
12	**Communication possibility**: A quick way to contact professional responders or emergency call operators	x	x
13	**Feedback**: The possibility to fill out a mission report	x	x

Test and Evaluation of Identified Functions

Nine of the identified functions were implemented in the prototype, and tested by the voluntary groups. Specifically, six functions were tested by both groups (see Table 3), and in addition, due to relevance and/or test limitations, two more functions were tested by citizen volunteers and one other function by semi-professional volunteers. For semi-professionals, the feedback function (No. 9) was only partly tested (in Test 1), where the only possible feedback was that the users could indicate why they had missed an alert. For the citizen volunteer tests, the volunteers could respond to a larger set of questions (in Tests 3 and 4).

Table 3. Functions implemented and tested in the smartphone application

No.	Function	Tested by semi-prof. volunteers	Tested by citizen volunteers
1	Check in/check out	x	*
2	Loud and unique signal	x	x
3	Information	x	x
4	Acknowledgement	x	x
5	Other voluntary responders	**	x
6	Navigation	x	x
7	Arrival status	x	x
8	Checklist	**	x
9	Feedback	Partly	x

**Not tested due to test limitations, **Not tested due to not being a priority for semi-professionals.*

Overall, the smartphone prototype functions satisfied the previously identified user needs – the responders received their alerts, acknowledged them, and followed the navigation system to the test incident site (physically or virtually, depending on the test).

The check in/check out function (No. 1) was only tested by the semi-professionals, who thought it was a good function to have since the application is running in the background, and it may not be sufficient just to turn it off. Both semi-professional volunteers and citizen volunteers commented that they missed alerts because they did not notice the signal or the vibration when their phone was in silent mode (No. 2). One semi-professional thought the vibration was too weak. Some citizen volunteers claimed that it was not loud enough and sounded like a regular notification. They emphasised that you need to be able to hear it even in noisy environments and when you do not have the phone right next to you; for example, by means of a blinking light, a stronger vibration and an even louder sound alert. In the AAR in Test 2, the semi-professionals stated that the amount of information about the incident (No. 3) was sufficient. Apart from complaints about the design of the application (confusing symbols and small text), no issues were reported for the acknowledgement function (No. 4). The ability to see who else accepts an assignment (No. 5) was greatly appreciated by citizen volunteers (in both Test 3 and Test 4).

In the application, if the user accepts the alert, an offer of navigational assistance is made; if accepted, Google Maps enabling navigation is launched (No. 6). The navigation aid is the same as in the existing solution for citizen volunteers (through a link in the SMS to Google Maps). Still, the citizen volunteers said that it was easier to access the map from the SMS, and that it should be possible to access the map in the application before the mission is accepted, as soon as the responders receive the incident information. The main reason for this is probably that their current system alerts everybody on the SMS list, and not only those who are actually close to the incident, as in the prototype application. There was also criticism of the navigation aid from the semi-professionals after Test 2, when one of the responders was doubtful whether he would have arrived at the right place if he had followed the instructions. Also, the possibility to indicate arrival at the incident site (No. 7) was forgotten by some volunteers – they did not remember to press the button.

The citizen volunteer responders stated that the checklist (No. 8) should be specific to each type of incident, and contain a limited amount of text. On the other hand, some citizen voluntary responders, as well as other semi-professional responders, said that they did not want to use any type of smartphone application at the emergency site, but needed to focus on the emergency work. Instead, they claimed that the checklist could be used as a preparatory tool, to remember what to do before an incident and during the travel to the incident site (if there was more than one responder travelling together).

Regarding the feedback function (No. 9), the citizen voluntary responders said that there were too many questions, and that the answers to some of them could easily be automated, e.g. arrival time. Also, they did not like the use of the word "debriefing" in the question: "Do you want debriefing?", and felt that this indicated that the responder might have psychological problems. It would be better to ask if they had identified any lessons that they would like to share or to have a routine to meet up for a cup of coffee after a response.

One of the citizen volunteer groups had already enhanced the SMS-based solution with additional smartphone applications; for example, by providing a loud and unique signal with flashing lights as well as GPS tracking and a position presentation for all responders. During Test 3, the citizen volunteers who were used to the enhanced SMS solution expressed negative opinions about the tested application and believed that it was difficult to use and not intuitive. The other citizen voluntary group in Test 4 (who had not developed additional

functionality) also said that the application was not user-friendly and that the button symbols were confusing, but at the same time they stated that the application, with its additional functionality, was a great improvement upon their current SMS solution. The semi-professionals were generally pleased and did not believe that they would have made much use of additional functionality in the application, but instead highlighted the value of training and education.

To sum up, the tests with citizen volunteers indicated that the two most important functions were the alert signal (No. 2) and the possibility to see who else is responding (No. 5). While an explicit ranking of the functions was never performed in the tests with semi-professionals, the ability to see who else responds was not highlighted as one of the more important functions. However, a loud and unique signal was also highlighted as crucial by the semi-professionals.

Evaluation: Identification of Additional Needs and Functions

The tests gave rise to new suggestions about needs and functions, which were discussed during the evaluation. The citizen volunteers also wanted to ***receive information about when professional responders will arrive*** (a similar function to No. 5 – to see who else has accepted an assignment). While the semi-professional responders agreed that it may be nice to know this, they did not rank it as vital information. One argument was that the incident in Test 2 took place in a city, where professional emergency services typically have a short response time. This may be compared to the citizen volunteers, who respond in a rural area involving long distances.

Another new need was to be able to ***see which equipment the responders are bringing***. Equipment that volunteers could be asked to bring to the incident site include automated external defibrillators (AEDs) and fire extinguishers. There were various ideas about how this need can be implemented as a function:

- Simple general information about what might be useful to bring to the specific type of incident.
- A status button, where the responder can indicate that he/she is bringing the equipment. This is particularly relevant for citizen volunteers, because some villages only have one AED; if somebody picks it up and indicates this, it might prevent others from losing time by going to get it as well instead of heading straight to the incident site.
- Assignment of equipment to responders, where the system decides which responder should bring each piece of necessary equipment, and informs responders of this through the application.

One of the semi-professional responders forgot to report his arrival in Test 2, giving rise to the suggestion that the application should be able to ***detect when a responder has arrived***, and log this automatically. Moreover, the ability to ***send coordinates from the incident site*** was suggested by both voluntary groups. This would be useful in cases where the exact location of the incident site is uncertain or approximate. Being the first on site, the voluntary responders could then easily send the correct coordinates to the professional responders so that they reduce their response time. To be able to ***send pictures and video from the incident site*** was discussed by both voluntary groups (in Test 2 and Test 3). The professional emergency personnel who supported the tests said that information from the incident site might be very useful, especially the number of victims.

From the tests with citizen volunteers, it became evident that the development of the application must take into account the ***technical maturity*** of the intended users. Many potential participants did not have an Android smartphone or could not download and install the application, which was a prerequisite to participate in Test 3. Of the ones who did participate, some had received help from friends or family to get ready.

The Same Solution for Different Volunteer Groups

The results indicate that the functionality offered by the tested smartphone application was sufficient for both volunteer groups, so the same solution can be used for different types of volunteers. While the majority of the identified functions were relevant to both groups, some differences emerged. The perceived relative importance of some functions differed, just like opinions about the design – not intuitive enough. It should be noted, though, that this partly might be due to the context; for example, citizen volunteers in Case 2 already had an existing, working solution (SMS) to compare the application with, or due to differences in test design, as Tests 1 and 2 were not performed in the same way as Tests 3 and 4. Thus, the study indicates that the basic ICT needs of different groups of voluntary first responders are similar and can mostly be implemented using the same functions. While some specific functions might differ, the same solution can easily be adapted to satisfy these, by adding, removing or revising some functions.

DISCUSSION: ICT AS AN ENABLER IN NEW FORMS OF GOVERNING AND CO-PRODUCTION

ICT opens up new forms of governing and improved resilience in public-service delivery, not least in emergency response. Volunteers can be engaged and collaborate with public bodies to improve services for others and themselves through co-production (Linders, 2012; Pestoff et al., 2012). However, in order to realise this co-production, suitable technological solutions are necessary. Although the ICT artefact and its surrounding collaborative infrastructure are closely interconnected, it can be fruitful to separate them and study the ICT artefact solely in order to enhance our understanding – especially if the context of the ICT artefact have already been explored (Alter, 2002).

Here, the involvement of end users is essential (Bjögvinsson et al., 2012). Still, there are few, if any, studies on co-production focusing on the ICT artefact with end-user involvement. In the information systems (IS) research field, on the other hand, there are some studies relating to user participation in emerging public-sector community initiatives (Bjögvinsson et al., 2012; Robertson and Simonsen, 2012). In the specific area of volunteers, emergency response and resilience, there exist studies on ICT solutions, but it is still difficult to find any in which suggested ICT functions and solutions are solidly anchored in user needs (e.g. Ringh et al., 2011; Schönböck et al., 2016). This study contributes explicitly in this respect, since it focuses on suitable functions of applications who are directly based on user involvement, user needs and user experience. As for emergency response, an ICT artefact that is well suited to volunteer first responders' opens up new possibilities for voluntary co-production whereby the resources of professional emergency services can be saved and used more effectively, and at the same time a quicker response is enabled. From a wider public-sector perspective, the study opens up space for an interesting merger of co-production and ICT perspectives, in line with studies claiming the benefits of a cross-fertilisation of policy science and information systems research fields in general (Janowski et al, 2012).

Identifying ICT Functions with End-User Involvement

Capturing the specific ICT functions can be difficult and time consuming. The number of identified functions became extensive. Initially, 13 functions were identified and after testing approximately half of them, an additional four functions were identified. Through the involvement of the volunteers – the end users – these functions could be divided into two groups: functions that are absolutely necessary and functions that might be nice but are possible to manage without. For example, in Case 2, the volunteer initiative had been running successfully for over two years when the tests were performed. This indicates that the basic SMS-based solution was actually sufficient for the intended purpose, implying the necessary functions to be only the ability to receive an alert and getting brief information about the incident, including the location. However, additional functionality might lead to a quicker and more effective response. For example, the volunteers may notice the alert more easily and quickly with a louder and unique signal. Another example is the ability to see who else is responding, which could make the volunteers more comfortable about responding themselves. This may make them more willing to continue to devote their time and also enhance the collaboration with professional emergency services. This again points to the benefits of connecting co-production and ICT artefacts based on end-user involvement. It may be cost-intensive and time-consuming at the beginning but will be worth it enabling a long-lasting way of governing the response.

Applicability of the Results: International Perspectives and Disaster Response

Given that many basic first-response tasks are similar globally (e.g. first aid, fire extinguishing), many of this study's results should be transferable to settings in other countries, for instance, importance of an intuitive interface is probably general. It is likely that volunteers will not use the application very often since they are only complementing the professional emergency services. Thus, the number of alerts that a voluntary responder can expect to receive are few; in the studied cases, often less than one per month. Therefore, the responders will not have the opportunity to learn to handle the application through frequent usage. Instead, it has to be sufficiently intuitive, or test alerts have to be sent regularly, for the volunteers to have the chance to learn to use the functions. Intuitive interfaces are also argued for in previous related studies (Lanerolle et al, 2010; Havlik et al., 2016). Similar functions are also highlighted, for instance use of acknowledgements, bringing equipment, possibility to share information (between volunteers and between volunteers and professionals) and possibility to get feedback (Auferbauer and Ganhör, 2015; Schmidt et al, 2018; Schönböck et al, 2016).

In a disaster response context, at least three possible user groups can be discerned: the ones who are already volunteers for everyday emergencies, and volunteers specific to a current disaster, either through some established non-profit organisation, or spontaneous volunteers (Havlik et al., 2016; Ringh et al., 2011; Whittaker et al., 2015). While disaster response volunteers connected to such organisations as the Red Cross might have the time and ability to become acquainted with an ICT solution like a smartphone application beforehand,

spontaneous volunteers will typically have no such experience. Thus, for this user group, the user friendliness of the application is even more crucial than when it is used for frequent, smaller emergencies (Falasca and Zobel, 2012).

CONCLUSIONS AND FUTURE WORK

This study set out to identify suitable functions in a smartphone application for volunteers in emergency response. The study's contributions thus relate mainly to the functions of the application, connected to the two voluntary groups in the meta-analysis. The study concludes that:

- Several functions were identified by both voluntary groups. Elementary functions comprised the ability to receive an alert on a mobile phone and receive sufficient information to be able to find the incident site. More specifically, this included functions as easy noticeable and unique alert signal, and an intuitive navigational aid to access and follow.
- However, there were also multiple functions identified that might contribute to the more effective utilisation of volunteers, reduce the first response times, and make the volunteers more comfortable in their role as first responders, making them willing to continue to devote their time, and enhancing the collaboration with professional emergency response organisations. Examples of functions for a more effective response and collaboration were a function indicating which equipment to bring, ability to send coordinates and pictures/videos from the incident site to professional resources, and – particularly for citizen volunteers – to receive information about when other responding resources will arrive.
- Different volunteer groups can use the same basic functions, but opinions about the design and realisation of the functions might differ depending on user background and context.
- Generally, it is a necessity for the application to be intuitive and easy to use, since most of the volunteers will be infrequent users and have varied technological literacy – if the users have a low technological maturity they may need education and support when installing and using the application.

Several functions were identified for the volunteers' ICT solution (the smartphone application) and, during the evaluation, new needs were also identified – which need to be further analysed and tested through exercises in order to arrive at implementable functions. Future work should address this, together with the professional response organisations and the Swedish PSAP.

At a more general level, the results of this study may be a useful input to research on the development of support for volunteers in emergency and disaster management. In this study, we also tried to open up space for the merging of ICT and various network perspectives, specifically co-production. While we only provide a starting point in this respect, the trait can be pursued in future research investigating the linkage of the respective perspectives further, from the macro-societal level, to theory development, to practical information systems development and inter-disciplinary design teams, not least concerning new emergency response volunteer initiatives.

REFERENCES

Agranoff, R. (2006) Inside Collaborative Networks: Ten Lessons for Public Managers. *Public Administration Review*, 66(1):56-65.

Agranoff, R. and McGuire, M. (2010) *Collaborative Public Management: New Strategies for Local Governments*. Georgetown University Press, Washington DC.

Alford, J. (2014) The Multiple Facets of Co-Production: Building on the Work of Elinor Ostrom. *Public Management Review*, 16(3): 299–316.

Alter, S. (2002) The Work System: Method for Understanding Information Systems and Information Systems Research. *Communications of the Association for Information Systems*, 9(6): 90–104.

Auferbauer, D. and Ganhör, R. (2015) Moving Towards Crowd tasking for Disaster Mitigation. In *Proceedings pestoffveof the ISCRAM 2015 Conference* – Kristiansand, Norway, May.

Berglund, E., Claesson, A., Nordberga, P., Djärva, T., Lundgren, P., Folke, F., Forsberg, S., Rivaa, G., Ringha, M. (2018) A smartphone application for dispatch of lay responders to out-of-hospital cardiac arrests. *Resuscitation* 126, 160-165.

Brandsen, T., Verschuere, B.B. and Steen, T. (Eds) (2018) *Co-Production and Co-Creation Engaging Citizens in Public Services*. Routledge, New York.

Björgvinsson, E., Ehn, P. and Hillgren, P. (2012) Design Things and Design Thinking: Contemporary

Participatory Design Challenges. *Design Issues*, 28(3): 101–116.

Börzel, T. (1998) Organizing Babylon – on the Different Conceptions of Policy Networks. *Public Administration*, 76(2): 253–273.

Carlsson, L. (2000) Policy Network as Collective Action. *Policy Studies Journal*, 28(3): 502–520.

de Lanerolle, T.R., Defabbia-Kane, S.,Gochev, D., Anderson, W.V., Fox-Epstein, E., Morelli, R.A. (2010) Development of a Virtual Dashboard for Event Coordination between Multiple Groups. In *Proceedings of the7th International ISCRAM Conference* – Seattle, USA, May.

Díaz, P., Carroll, J. M. and Aedo, I. (2016) Coproduction as an Approach to Technology-Mediated Citizen Participation in Emergency Management. *Future Internet*, 8(3): 41.

Falasca, M. and Zobel, C. (2012) An Optimization Model for Volunteer Assignments in Humanitarian Organizations. *Socio-Economic Planning Sciences*, 46(4): 250–260.

Ferguson, H.T., Gesing, S. and Nabrzyski, J. (2016) Measuring Usability in Decision Tools Supporting Collaborations for Environmental Disaster Response. In *49th Hawaii International Conference on System Sciences*, Koloa, HI, USA, 5–8 Jan., pp. 2873–2881.

Flyvbjerg, B. (2006) Five Misunderstandings About Case-Study Research, *Qualitative Inquiry*, 2006 12:219.

Gomez, E.A. and Murray Turof, M. (2007) Community Crisis Response Teams: Leveraging Local Resources through ICT E-Readiness. In *Proceedings of the 40th Hawaii International Conference on System Sciences – (HICSS'07)*, Waikoloa, HI, USA, 3–6 Jan., pp. 1530–1605.

Havlik, D., Pielorz, J. and Widera, A. (2016) "Interaction with Citizens" Experiments: From Context-aware Alerting to Crowdtasking. In *Proceedings of the ISCRAM 2016 Conference*, Rio de Janeiro, Brazil, May.

Jaeger, P.T., Shneiderman, B., Fleischmann, K.R., Preece, J., Qu, Y., and Wu, F.P. (2007) Community Response Grids: E-government, Social Networks, and Effective Emergency Response. *Telecommunications Policy*, 31: 592–604.

Janowski, T., Pardo, T.A. and Davies, J. (2012) Government Information Networks: Mapping Electronic Governance cases through Public Administration Concepts. *Government Information Quarterly* 29: S1–S10. Editorial.

Johansson, R., Danielsson, E., Kvarnlöf, L., Eriksson, K., and Karlsson, R. (2018) At the External Boundary of a Disaster Response Operation: The Dynamics of Volunteer Inclusion. *Journal of Contingencies and Crisis Management*, 26 (4):519-529.

Linders, D. (2012) From E-government to We-government: Defining a Typology for Citizen Coproduction in the Age of Social Media. *Government Information Quarterly*, 29: 446–454.

Linton, J.D. (2002) Implementation Research: State of the Art and Future Directions. *Technovation*, 22: 65–79.

Loukis, E., Janssen, M., Dawes, S. and Zheng, L. (2016) Evolving ICT and Governance in Organizational Networks: Conceptual and Theoretical Foundations. *Electronic Markets*, 26: 7–14.

Meissen, U., Jendreck, M., Hardt, M., Fuchs-Kittowski, F., Pfenningschmidt, S. and Voisard, A. (2017) A general system architecture and design for the coordination of volunteers for agile disaster response. In *14th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*, Albi, France, May.

Mojir, K.Y., Pilemalm, S., Andersson Granberg, T. (2018) Semi-Professionals: Emergency Response as an Additional Task in Current Occupations. *International Journal of Emergency Services*, https://doi.org/10.1108/IJES-11-2017-0059.

Myers, M. (2009) *Qualitative Research in Business and Management*. Sage, Los Angeles.

Ostrom, E. (1996) Crossing the Great Divide: Coproduction, Synergy, and Development. *World Development*, 24(6): 1073–1087.

Pestoff, V., Brandsen, T. and Verschuere, B. (Eds.) (2012) *New Public Governance, the Third Sector, and Co-Production*. Routledge, New York.

Ramsell, E., Pilemalm, S. and Andersson Granberg, T. (2017) Using Volunteers for Emergency Response in Rural Areas: Network Collaboration Factors and IT Support in the Case of Enhanced Neighbors. In *14th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*, Albi, France, May.

Ringh, M., Fredman, D., Nordberg, P., Stark, T. and Hollenberg, J. (2011) Mobile Phone Technology Identifies and Recruits Trained Citizens to Perform CPR on Out-of-hospital Cardiac Arrest Victims Prior to Ambulance Arrival. *Resuscitation*, 82: 1514–1518.

Roberts, A., Nimegeer, A., Farmer, J., and Heaney, D.J. (2014) The Experience of Community First Responders in Co-Producing Rural Health Care: In the Liminal Gap between Citizen and Professional. *BMC Health Services Research*, 14: 460.

Robertson, T. and Simonsen, J. (2012) Challenges and Opportunities in Contemporary Participatory Design. *Design Issues*, 28(3): 3–9.

Schmidt, A., Wolbers J., Ferguson, J. and Boersma, K. (2018) Are you Ready2Help? Conceptualizing the Management of Online and Onsite Volunteer Convergence. *Journal of Contingencies and Crisis Management*, 26: 338–349.

Schönböck, J., Raab, M., Altmann, J., Kapsammer, E., Kusel, A., Pröll, B., Retschitzegger, W. and Schwinger, W. (2016) A Survey on Volunteer Management Systems. In Proceedings of 2016 49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI, USA, 5–8 Jan., pp. 767–776.

St. Denis, L. and Hughes, A. L. (2018) Crisis Cleanup: Creating a Virtual Command Post to Support Relief Organizations on the Ground. In *Proceedings of the 15th ISCRAM Conference* – Rochester, NY, USA May.

SOU - Official Report from the Swedish Government (2018) En effektivare kommunal räddningstjänst räddningstjänst [A more effective municipal emergency service], 2018:54.

Sund, B. and Jaldell, H. (2018) Security Officers Responding to Residential Fire Alarms: Estimating the Effect on Survival and Property Damage. *Fire Safety Journal*, 97: 1–11.

Venema, A., Groothoff, J. and Bierens, J. (2010) The Role of Bystanders during Rescue and Resuscitation of Drowning Victims. *Resuscitation*, 81(4): 434–439.

Whittaker, J., McLennan B. and Handmer, J. (2015) A Review of Informal Volunteerism in Emergencies and Disasters: Definition, Opportunities and Challenges. *International Journal of Disaster Risk Reduction*, 13: 358–368.

ACKNOWLEDGMENTS

This study was made possible through funding from the Swedish Civil Contingencies Agency (MSB) and Norrköpingsfonden.

Trends in Humanitarian Health Information during the 2010 Haiti Earthquake: Motivation for Curating Domain Knowledge Bases

Jennifer L. Chan
Northwestern University
jennifer-chan@northwestern.edu

Gabriel Nam
University of Pennsylvania
nam.gabriel@gmail.com

Allison G. Marshall
Temple University
gibsonmarshall@gmail.com

Hemant Purohit
George Mason University
hpurohit@gmu.edu

ABSTRACT [150]
Health response plays a major role during disasters and information management plays a crucial role in situational awareness to adapt to evolving needs. Health organizations exchange information often through narrative-based documents called situation reports. Although situation reports are widely shared, they are an increasingly challenging information source from which to infer knowledge for situational awareness. This paper analyzed health information from traditional health reports using mixed methods during the aftermath of the 2010 Haiti Earthquake and provides insights into the patterns of what's being said, how it's being said, and trends over time. Opportunities lie ahead to analyze narrative documents at scale by combining human knowledge from qualitative coding with machine intelligence. In addition, developing unifying health domain ontologies representing diverse humanitarian health concepts will advance computational techniques to improve the efficiency and accuracy of retrieving knowledge for improved situational awareness and potential decision making during humanitarian health response.

Keywords
Information management, health information, knowledge bases, curation

INTRODUCTION

Information Management and Humanitarian Health Response

Information management during disasters and humanitarian response plays a crucial role in maintaining situational awareness, adapting to post disaster evolving needs, and coordinating with local, national, and international responding agencies. (Crowley and Chan, 2011; OCHA, 2002; Waugaman and Fast, 2016)

WiPe– Community Engagement & Healthcare Systems
Proceedings of the 16th ISCRAM Conference – València, Spain May 2019
Zeno Franco, José J. González and José H. Canós, eds..

Recognized by many agencies as playing a central role to the response system, information management remains a challenge across many sectors including health. (Crowley and Chan, 2011; Goyet et al., 2011; Van de Walle and Comes, 2015; Waugaman and Fast, 2016)

Rapid collection and dissemination of key information including infrastructure assessments, morbidity, and mortality statistics are key factors which influence effective decision making during a humanitarian health response. However, environmental, political, and cultural contributing factors influence how information is collected and shared among responding organizations and humanitarian actors. (Morton and Levy, 2011; Van de Walle and Comes, 2015) In particular, the fragmented nature of a disaster response, underdeveloped models of information management, and limited information sharing have been cited as contributing factors to a hampered response. (Altay and Labonte, 2014; World Health Organization, 2009; Waugaman and Fast, 2016)

The 2010 Haiti Earthquake marked a turning point for technology and information exchange but also highlighted major challenges in information sharing among new actors, including persistent cultural behavior barriers of information and data sharing. (Crowley and Chan, 2011; US Department of State, 2010) The World Health Organization's (WHO) post-earthquake report recognized that "information and coordination management was a challenge that was not met adequately." (Goyet et al., 2011) The 2014 West Africa Ebola response marked another series of information management (IM) challenges, where the complexity and unchartered nature of the Ebola response highlighted systemic shortcomings in IM. (Comes et al., 2015; Engel et al., 2007; McDonald, 2016; Waugaman and Fast, 2016) Early paper-based data collection, colliding information systems, and static information reports from responders in affected countries were all cited challenges in this unprecedented humanitarian health crisis.

In the diverse environment of information generation, sharing, and coordination, the United Nations Office of Coordinating Humanitarian Affairs (OCHA) plays a central role in coordination and information management in disasters and humanitarian crises where they are activated. Their mission is to "coordinate(s) humanitarian action to ensure crisis-affected people receive the assistance and protection they need", with information management as one of its major efforts to achieve these goals. It is "responsible for consolidating and publishing information across the spectrum of humanitarian response." (OCHA, 2019) Information management principles that stem from overarching humanitarian principles help guide standardized tools and products for which regional and country offices aim to provide focused, timely, and relevant information during the response. (OCHA, 2002; OCHA, 2018)

Health response plays a major role during disasters and humanitarian crises, from minimizing mortality due to infectious diseases (e.g., malaria, diarrhea, ebola) and mitigating morbidity by providing essential health services (e.g., maternal child health, chronic diseases, mental health). Health organizations exchange information often through various channels such as emails, in-person meetings, documents, and at times web-based platforms. The WHO acts as the lead agency for the health cluster in collaboration with OCHA to facilitate the sharing of health information during crises when the OCHA acts as a coordinating body. The WHO also oversees activated health clusters around the world and, according to the 2018 response framework, aims to "Ensure[ing] the best possible information, analysis and understanding, and facilitating coordination." (WHO, 2008) At the end of 2018, 27 countries around the world have clusters which are working to coordinate health response activities with host nations and NGOs to deliver health programming. (WHO, 2008)

Situation Reports

Situation reports, or "sitreps", are documents that are shared among humanitarian actors that aim to provide an overview of a response. (Finn et al., 2018; Finn and Oreglia, 2016; Van De Walle and Muhren, 2009) These documents have been used for well over a decade, and they are as numerous as they are diverse. These narrative

documents are created by NGOs, government agencies, and UN organizations, to name a few. (King, 2005) While there is no single standardized situation report, these documents provide an overview of the disaster/humanitarian crisis. (Zhang et al., 2002) Health situation reports frequently provide available mortality statistics, an overview of diseases of epidemic potential, public health efforts, medical supply chain logistics, and an overview of which health organizations are working where and with what specific focus (i.e., 3W). Depending upon the crisis or disaster, health sitreps are generally updated daily, weekly, biweekly or monthly. Documents, often in PDF or word doc formats, are short narrative documents that may also include maps, tables and graphs and are shared either publicly or privately depending upon the organization or group. (Finn and Oreglia, 2016) They are intended to update responding actors and aim to influence coordination and decision-making. While situations reports are commonly created, shared and perceived as useful by some responders, they have been cited as difficult to analyze in the ever increasing environment of information and data overload. (Finn and Oreglia, 2016; Zhang et al., 2002) Despite criticism by some actors that "sitreps are a thing of the past" the situation reports continue to be created by many stakeholders despite ongoing challenges and criticisms. (Finn et al., 2009a)

Previous studies have investigated the production and labor investments in primarily UN agency situation reports through qualitative interviews. (Finn and Oreglia, 2016) Perceptions of IM challenges have also been studied using interpretive case study methodologies with four individuals involved in the 2010 Haiti earthquake response. (Van de Walle and Dugdale, 2012) Grey literature publications also provide an early view of content analysis of situation reports focusing on coding "meta data" of information types (e.g., date of production, disaster type, information structure) (Finn et al., 2009b) To date, there has been fewer published studies that perform an in depth analysis of the narrative content in situation reports as it relates to a specific sector of response. (Dhillon and Annunziata, 2012), A document review of PAHO and health cluster documents determined the epidemiological completeness of these documents, but did not assess other health sector content such as coordination, essential health services, and medical logistics.

This paper describes an analysis of health situation reports and similar documents called health bulletins distributed during the early phase of response from one of the largest recent humanitarian crises in the past decade. While previous peer-reviewed and non peer-reviewed literature has explored the practice and perceived usefulness of situation reports, this study explores the trends of health information within the content of these narrative documents. It also focuses on the health content as part of the IM paradigm, and not only how health information is presented in these public documents over time but to what degree they align with known humanitarian health response themes and terms. Lastly, it aims to complement published literature that frequently focuses on general IM and coordination.

The 2010 Haiti Earthquake

In January 2010, a 7.0 magnitude earthquake struck 13 miles west of Port-au-Prince. With estimates of 220,000 dead, more than 300,000 injured, and billions of USD in damages, Haiti caught the attention of the world in a single day. (Goyet et al., 2011; Zhuang et al., 2012) Thousands of health agencies arrived less than three weeks after the earthquake. The influx of international aid resulted in unprecedented coordination challenges. Though the actors worked to meet immediate needs, the number of unprepared stakeholders overwhelmed coordination efforts. The fragmented nature of the response, disorganized models of information management, and other factors have led some observers to describe the information and coordination efforts in Haiti as "a challenge that was not met adequately". (Altay and Labonte, 2014; Goyet et al., 2011) The World Health Organization (WHO) and Pan American Health Organization (PAHO) led the Global Health Cluster. WHO/PAHO helped to coordinate non-governmental organizations (NGOs) alongside Haiti's Ministry of Health and Population, to manage medical supply chain logistics, and hold daily coordination meetings. The Health Cluster and PAHO

were also designated to produce publicly available bulletins detailing information that reflected operational and coordination field activities along with guidelines. These reports provide a unique opportunity to qualitatively and quantitatively analyze trends in health information.

METHODS

Mixed methods of qualitative and quantitative content analyses were used in the study. Forty-nine publicly available situational reports were collected from the WHO (n=23) and PAHO (n=26) from January 13th to April 15th, 2010. The study was reviewed by the Northwestern University Institutional Review Board and was consider exempt. A qualitative codebook was created using an integrated approach employing both inductive and deductive methods to develop and modify codes as described by Bradley. (Bradley et al., 2007) A list of themes was created using humanitarian health guidelines widely accepted within the global health sector, including *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response* and Médecins Sans Frontières' *Refugee Health: An Approach to Emergency Situations*. The resultant *a priori* codebook was then revised using an iterative inductive (grounded theory) method as the reports were reviewed. (Glaser and Strauss, 1967; Strauss and Corbin, 1990)

Prior to applying the code structure to the data corpus, four articles were randomly selected using an online random number generator. Two coders separately reviewed the selected articles and finalized the codebook by accommodating new themes, clarifying ambiguous definitions of codes, and eliminating redundant codes. The final terms were organized into 12 [major codes] (e.g., injuries, health infrastructure, medical logistics, and essential health services) and 61 'minor codes' (e.g., mental health, mobile clinics, rehabilitation services, shelter). A third coder was trained until a sufficient intercoder reliability ratio was achieved using the Kurasaki approach. (Kurasaki, 2000) The Kurasaki method enables coding of free flowing content or text that may have overlapping themes. Each coder reviewed and applied the codes to five randomly selected articles separately. The unit of analysis for codes were idea units also called meaning units, most frequently in the form of sentences. The intercoder reliability ratio was found to be 0.71, using the method described by Kurasaki. (Kurasaki, 2000) This method measures the agreement across the three coders for each theme by calculating a ratio of agreements to disagreements. Overall agreement is calculated by averaging agreements across all themes. Codes were applied to the data corpus using computer software QSR NVivo for Macintosh (QSR International Pty Ltd, Doncaster, Victoria, Australia) by assigning thematic codes and sub-codes to sections of text.

The three coders met to discuss individual major codes, minor sub-codes, and cross-references. Themes and qualitative trends were discussed and recorded including examples of content that reflected the findings. Descriptive analytics of major and minor codes were then performed using Tableau 9.0 software (Seattle, Washington, USA).

RESULTS

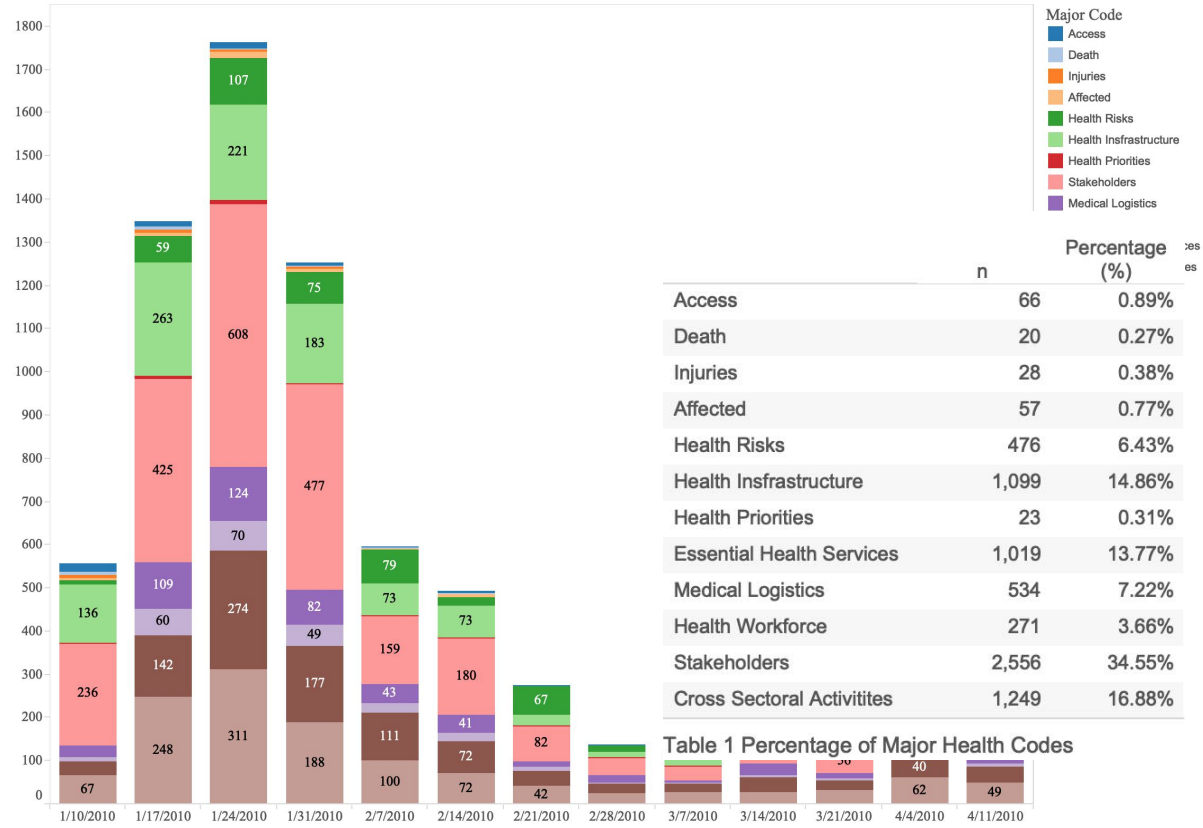
Overview

7,398 codes were applied to 26 PAHO health reports and 23 health cluster bulletins from January 13th to April 15th, 2010. Almost half of the codes occurred in the PAHO reports (45.3%), with a majority of the codes occurring in the health cluster reports (54.7%). All major codes from the qualitative codebook were included and 3,606 codes were minor codes. Only 2 minor codes 'health facility-closed' and 'protection' were not identified in the data corpus during the study period. The top three minor codes were stakeholder subgroups (i.e., 'Haitian government', 'NGOs', and the 'Health Cluster'). 'Water and sanitation' and 'shelter', closely related sectors of response, were frequently cited. The most frequent health infrastructure minor code was

'permanent hospital'.

Two themes were qualitatively analyzed, [access] and 'Haitian government', and are discussed later in this manuscript. Codes related to [access] occurred primarily during the first few weeks of the response. The minor code 'Haitian government' occurred 260 times during the study period as part of the [stakeholder] major code which was the most frequently coded term in the study (n=2556).

General Prevalence of Health Topics



	n	Percentage (%)
Access	66	0.89%
Death	20	0.27%
Injuries	28	0.38%
Affected	57	0.77%
Health Risks	476	6.43%
Health Insfrastructure	1,099	14.86%
Health Priorities	23	0.31%
Essential Health Services	1,019	13.77%
Medical Logistics	534	7.22%
Health Workforce	271	3.66%
Stakeholders	2,556	34.55%
Cross Sectoral Activitites	1,249	16.88%

Table 1 Percentage of Major Health Codes

Figure 1 Prevalence of Major Health Codes

The four most common major codes were [stakeholders], [cross sectoral activities], [health infrastructure] and [essential health services]. (Table 1) Major codes peaked during the first month of the study period reflecting both the intense reported needs and growth of health response activities. (Figure 1)

Essential health Services

Essential health services are considered a core pillar of humanitarian health response. (Sphere Association, 2018; UNHCR, 2011; WHO, 2008) There were 1,019 essential health services codes throughout the study period. 11 subtypes of essential health services were analyzed (i.e., minor codes) which provided a more detailed content analysis over time. Minor codes included 'urban search and rescue', 'maternal child health', and 'rehabilitation services', to name a few. References to urban search and rescue occurred during the first 2 weeks of the response, while trauma care peaked during the

ESSENTIAL HEALTH SVCs	543
Trauma/Injury	75
HIV/TB	26
Primar Care	57
Post Op Care	48
RH/Sexual	26
Rehab Svc	34
MH	42
OB/MCH	37
Immun/Vacc	56
USAR	7
Surveillance	68
Grand Total	1,019

Table 2 Essential Health Services Codes

second week and primary care and post-operative care codes increased during the third week. Based upon the minor code pattern analysis, at the end of the study period, approximately two months after the earthquake, immunization, surveillance activities, and mental health predominated as essential health services.

Medical Logistics

Healthcare logistics including provision of materials, medications, and human resources are all major contributing factors to health response during a disaster. These functions are considered a key to the planning and management of the WHO. (WHO, 2008) Despite the sector's recognition of the important role of logistics, bottlenecks are often an ongoing challenge. (Jacob et al., 2008) During the 2010 Haiti response, the ability to procure and distribute medical supplies was believed to be a critical factor in the efficiency of the health response. (Inter-agency Standing Committee, 2018)

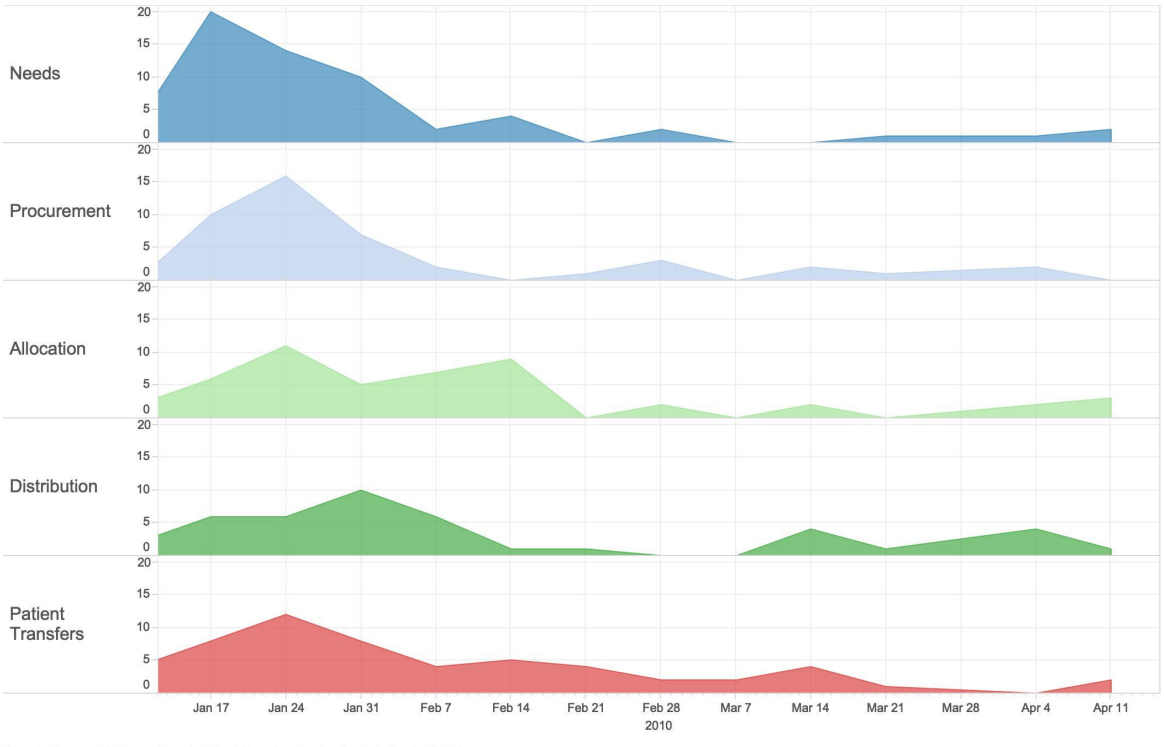


Figure 2 Temporal Patterns of Medical Logistics Minor Codes (Jan. 10 - Apr. 15, 2010)

There were 250 minor codes (i.e., 'needs', 'procurement', 'allocation', and 'distribution') providing a more in-depth analysis of medical logistics. Figure 2 depicts the patterns of these minor codes during the study period, indicating early findings that the narrative of logistics needs occurred prior to the subsequent content, reflecting procurement, allocations, and distributions over time.

Health Infrastructure

Understanding the status of health facilities was a major part of the humanitarian response in the aftermath of the Haiti earthquake. Over 60% of the hospitals in affected areas were damaged, and the Ministry of Health's

main building was also destroyed. (Jacob et al., 2008) Damage to permanent hospitals and the constantly changing status of field hospitals and mobile clinics posed a major challenge in coordination. As temporary health facilities became operational, health responders continued to struggle to understand which facilities were open and what services they were able to provide to patients.

There were 1,099 codes related to health infrastructure for which 348 codes could be further specified to minor codes such as 'permanent hospital', 'mobile clinic', or 'primary care clinic'. During the second week of the response, all minor codes peaked, similar to other codes, likely reflecting increased communications and reporting to health coordinating agencies as well as an overall increased awareness of health needs by a multitude of health responders. Codes reflecting field hospitals predominated during the first month of the response, while mobile health clinics increased during week two with sustained references for the following weeks. Permanent hospital was the minor code reported with the most frequency through the study period.

Qualitative Analysis

The qualitative analyses in social science and health sciences enables a more in-depth content analysis of topics enumerated by quantitative analysis of coded content (e.g., number of major and minor codes over time). These social science techniques bring forth human interpretation and knowledge of the public health medical and disaster domains for which simple enumeration and processing techniques cannot achieve.

Access

Access to affected populations in large scale natural disasters and complex humanitarian crises is a priority. (Bigot et al., 1997; Brennan and Nandy, 2001) Content analysis of the major code [access] appears earlier in the study period, occurring primarily in the first few weeks of the response with a peak period in week one. Qualitative analysis of this theme describes limited road and air access as a major operational challenge that contributed to overcrowding and further damage to healthcare infrastructure.

"The airport is intermittently open and closed. In addition, supplies arriving into the country are piling on the tarmac"

"Logistical challenges still remain at the airport in Port-au-Prince, where many supplies are offloaded with the expectation that they will be transported to relief agencies"

"Roads in Port-au-Prince are extremely difficult to navigate due to rubble and large amounts of people. Roads from the border with the Dominican Republic to the Port-au-Prince appear to be open"

"The airport is open for humanitarian flights only. There are reports of planes not being able to land or having to be diverted to other countries due to congestion on the only functional airstrip."

Over time, status updates (i.e., open and closed roads) are described with the likely intention of providing situational awareness for responding agencies.

"the road is being repaired between Jacmel and Port-au-Prince"

"The southern pier at the port in Port-au-Prince is functioning for humanitarian cargo only, but not at full capacity"

"the priority objective is to deliver health care services should a department become isolated from

other communes due to road flooding"

Stakeholders: The Haitian Government

The role of the Haitian government in the broad response has been discussed widely. (Grünewald et al., 2010; University of Haiti, 2011) Severe damage to Port-au-Prince left many major government agencies and staff directly affected. Situational awareness of the host nation's response in the early days was reported as limited and sparse.

Quantitative analysis of 'Haitian government' content from PAHO and health cluster reports show a similar trend to the overall trend of general codes, increasing in the first weeks after the response. (Figure 4) 'Haitian government' compared to other stakeholders is mentioned consistently throughout the study period. However, 'Haitian government' is mentioned only 7 times during the first week compared to PAHO (n=25), NGOs (n=34), and the UN (n=29).

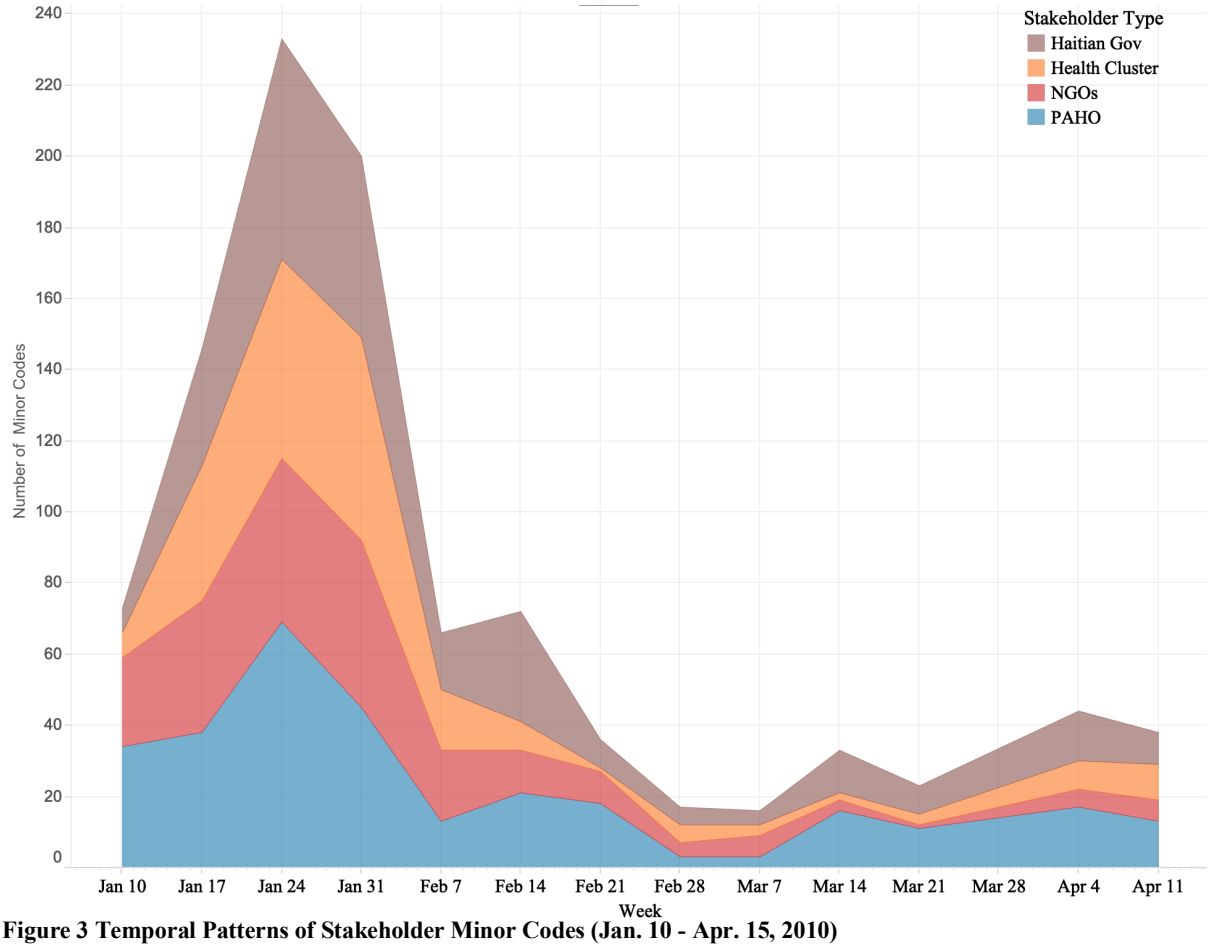


Figure 3 Temporal Patterns of Stakeholder Minor Codes (Jan. 10 - Apr. 15, 2010)

Qualitative analysis of the stakeholder minor code 'Haitian government' highlights the type of coordination efforts between UN actors, non-governmental organizations and other stakeholders. It also shares information on other response activities related to health programming (i.e., water services) and acts as an information channel to disseminate broader government strategic planning and collaboration during the post disaster phase into recovery.

"In order to enhance coordination between health actors, information on the location and services offered by organizations will be presented to Haiti's Prime Minister today, Friday"

"The Minister of Culture and Communication announced that the Government of Haiti is planning to issue a regular bulletin detailing ongoing humanitarian activities"

"The Clinton Foundation, in collaboration with the Ministry of Health, is contacting all organizations listed on the 'who, what, where' sheet who have medical staff in the country to find out exactly how many and which institutions are working"

"The Ministry of Health's strategy for the coming weeks shifts from focusing on emergency surgical cases to primary health care, health centers and hospitals. All health partners in Haiti support this strategy"

"WHO is collaborating with the Direction Nationale pour I'Eau Potable et I'Assainissement (DINEPA) on water quality"

"The Ministry of Health established a mental health group that will create a work plan for psychological support"

CONCLUSION

This study analyzed trends in health information from traditional health reports using mixed methods. Situation reports from the health cluster and PAHO were collected and qualitative codes applied to the corpus of information from January 13th to April 15th, 2010. Using a qualitative codebook, 7,398 codes resulted during the study period. [Stakeholders], [cross-sectoral activities], [health infrastructure], and [essential health services] were the most prevalent codes reflecting the sector priorities during the response. Temporal pattern analysis of enumerated codes showed a general increase in reporting of health content in the first few weeks of the response, with limited information about the Haitian government response in the first week. Specific codes such as [access] peak early, and persist over time but are less prevalent as the response continues compared to other health topics such as [health infrastructure] and [medical logistics]. The presented results and analyses help define the categories of relevant health information to create new and refined existing machine learning methods, which could extract health information from unstructured data at scale for disaster information management.

Lesson Learned

While temporal pattern analyses over time enumerate the health sector's current operational priorities and challenges, qualitative analysis provides further insights and specificity to the priorities, services, and coordination among stakeholders. Qualitative analysis of one major code [access] and one minor code 'Haitian government' provide more in-depth insights into specific access restrictions, road status updates, and coordination efforts with the host nation as well as the government's strategic planning going forward. IASC's six month report noted that the government "felt that despite the colossal achievement in re-establishing themselves hours after the earthquake, they were neither supported nor sufficiently recognized by the international community". (IASC, 2018) The relative absence of 'Haitian government' in situation reports during the first week, compared to 'PAHO'. 'NGOs', and 'UN' supports this conclusion. Additional situation report analysis from other actors (i.e., NGOs, local actors, government sitreps) may provide further insight.

Few studies have analyzed situation reports from a health focused perspective, investigating content type and trends over time. The health sector plays a significant role in large scale natural disasters and humanitarian crises, producing both internal and public situation reports. This study provides not only early findings of health

information trends over time, using the 2010 Haiti Earthquake as an example, but also employs two complementary methods of analysis, qualitative coding and descriptive statistics. This mixed method approach allows for temporal pattern analysis as well as more in-depth analysis of the narratives found in situation reports.

Situation reports continue to be an almost ubiquitous information source in humanitarian response, generated, produced, and shared broadly. The narrative format of sitreps coupled with the sector's daily, weekly, and bimonthly sharing practices through digital means creates an overwhelming information overload for those who seek situational awareness through these documents. This contributes to the broader challenges humanitarians face with information overload. The narrative format of situation reports further complicates one's ability to acquire knowledge for decision-making at the current scale of production and sharing. As disasters and humanitarian crises increase in both scale and frequency, the volume of narrative content that exists in the form of sitreps can be overwhelming for both understanding the nature of crises as they unfold in near-real time and retrospectively reflecting on lessons learned to transform the way forward.

Although perceived by many to be "useless", others throughout the sector continue to require sitrep generation and many more seek them out during crises. Regardless of the various positions on the value add of sitreps, or the published literature that reflects evidence on the perceived value of these documents, this study aims to further the understanding of "what is being said" in these health sector documents through a mixed methods research approach with a specificity and focus on health. Utilizing a qualitative coding framework from humanitarian operational handbooks to analyze trends during the crisis response, this study begins to reveal what factors influence health and humanitarian decision making during early phase response.

Future opportunities

This research provides early insights into the patterns of "what is being said", "how it's being said", and information and communication trends over time. Opportunities lie ahead to harness insights from these potential health narrative documents at scale, by expanding the scope of information to multiple disasters and other relevant sources of health information. The presented results and the codebooks allow the definitions of relevant health information categories for which machine intelligence could be built upon to extract health information at scale. Using advanced computational methods will provide a crucial and complementary approach with which to scale. In particular, we envision three key areas of future research investigations in the short term.

First, the exploitation of relevant, complementary data sources from the relevant response sectors such as situational reports from the logistics, shelter, water, and sanitation sectors would complement and enrich the overall knowledge acquisition process of health IM systems. Often, the knowledge required by health response operations is dependent on other sectors, thus systems that capture, analyze, and integrate information from related sectors will provide more targeted and comprehensive situational awareness for action-oriented decision-making. One of the largest humanitarian information repositories in the world, humanitarianresponse.info, represents a small fraction of overall situation reports that can be structured and analyzed for health information across both natural disasters and complex emergencies. Nonetheless, there are 10,987 publicly available situation reports and humanitarian bulletins in h for which to analyze and build a knowledge base not yet achieved to date for health in humanitarian response.

Second, we need to develop unifying health domain ontologies to represent the diverse concepts of humanitarian health information management unambiguously and seamlessly for both humans and machines/automated systems, with a focus on humanitarian actors. While human intelligence has contributed in developing a variety of coding schemes and lexicons for qualitative-quantitative analyses, such resources, unfortunately, remain

siloed and primarily non-interoperable for the tasks of information management. In addition further exploratory studies are needed to investigate and build more lexicons and taxonomies (i.e., schemes of classifying health terms) that associate health with key related sectors such as logistics and shelter in humanitarian response. For example, 66 logistics cluster situation reports and similar narrative documents, and 67 shelter cluster reports from the 2010 Haiti response are publicly available. Such ontologies will help transform the unstructured situation report data from various sources into uniform structured information that can easily be harnessed by advanced computing methods integrated across different systems for interoperability.

Lastly, there is a need to validate existing computational methods and design novel approaches to extract health information at scale from the large variety of existing data sources. While it is challenging to utilize these computational methods in real time given the complexity of relevant health information, state of the art methods of pattern recognition, natural language processing, and machine learning provide a good starting point for structuring the narrative. By using unstructured health information across various narrative information environments, including non-traditional sources such as social media, there is opportunity to extract health information and initiate timely analytics. Also, to further analyze large scale narrative information sources, such as situation reports, across various crises, we need to combine the power of human knowledge embedded in traditional qualitative coding with the automated systems. Automated systems, specifically machine intelligence, have the ability to extract relevant health information for a specific event at scale. More studies are needed for analyzing multiple disasters and humanitarian crises (e.g., Nepal Earthquake, Kerala Floods, West Africa and DRC Ebola responses) to further understand common health priorities as well as unique public health and medical needs for designing such universal qualitative codes, which can eventually be integrated into automated systems with machines that identify patterns for information categorization and knowledge management for health.

ACKNOWLEDGMENTS

We would like to thank Kate Bruni for her assistance in formatting the bibliography, and editing of the manuscript for grammar, formatting and punctuation.

1. Altay, N. and Labonte, M. (2014) Challenges in humanitarian information management and exchange : evidence from Haiti. *Disasters*, 38(s1), 50–72.
2. Bigot, A., Blok, L., Boelaert, M., Chartier, Y., Corign, P., Davis, A., Deguerry, M., Dusauchoit, T., Fermon, F., Griekspoor, A., Henkens, M., Huart, J.-P., Jean, F., Moren, A., Mustin, J.-P., Ostyn, B., Paquet, C., Saive, F., Scholte, P., Sohier, N., Van De Put, W., Van Der Kam, S., Van Der Borght, S., Van Praet, S. and Wuillaume, F. (1997) Refugee Health: An Approach to Emergency Situations. Medecins Sans Frontieres, London, England, 1-384.
3. Bradley, E. H., Curry, L. A. and Devers, K. J. (2007) Qualitative Data Analysis for Health Services Research: Developing Taxonomy, Themes, and Theory. *Health Services Research*, 42, 4, 1758–1772.
4. Brennan, R. J. and Nandy, R. (2001) Complex humanitarian emergencies: A major global health challenge. *Emergency Medicine*, 13, 147–156.
5. Comes, T., Van De Walle, B., Laguna, L. and Lauras, M. (2015) Understanding the Health Disaster: Research Design for the Response to the 2014 West African Ebola Outbreak. *Procedia Engineering*, 107, 81–89.
6. Crowley, J. and Chan, J. (2011) Disaster Relief 2.0: The Future of Information Sharing in Humanitarian Emergencies. *United Nations Foundation and Vodafone Foundation Partnership*.
7. Dhillon, P. and Annunziata, G. (2012) The Haitian Health Cluster Experience: A comparative

evaluation of the professional communication response to the 2010 earthquake and the subsequent cholera outbreak. *PLoS Currents*, Edition 1, 1–20.

8. Engel, C. C., Locke, S., Reissman, D. B., DeMartino, R., Kutz, I., McDonald, M. and Barsky, A. J. (2007) Terrorism, trauma, and mass casualty triage: how might we solve the latest mind-body problem? *Biosecurity and bioterrorism : biodefense strategy, practice, and science*, 5, 2, 155–163.
9. Finn, M. and Oreglia, E. (2016) A Fundamentally Confused Document: Situation Reports and the Work of Producing Humanitarian Information. *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing - CSCW '16*, 1347–1360.
10. Finn, M., Oreglia, E., Rabinowitz, N. and Ward, J. (2009a) *Situation Reports at OCHA*.
11. Finn, M., Oreglia, E., Rabinowitz, N. and Ward, J. (2009b) *Situation Reports at OCHA: Annexes*. Berkeley, CA.
12. Glaser, B. G. and A. L. Strauss. (1967) The Discovery of Grounded Theory: Strategies for Qualitative Research.Aldine De Gruyter, New York, NY, 1-282.
13. Goyet, C. D. V. De, Sarmiento, J. P. and Grünewald, F. (2011) *Health response to the earthquake in Haiti*. *Pan-American Health Organization*, 1-180.
14. Grünewald, F., Binder, A. and Georges, Y. (2010) Inter-agency real-time evaluation in Haiti: 3 months after the earthquake. 1-93.
15. Inter-agency Standing Committee. (2018) Response to The Humanitarian Crisis in Haiti. 1-44.
16. Jacob, B., Mawson, A. R., Payton, M. and Guignard, J. C. (2008) Disaster mythology and fact: Hurricane Katrina and social attachment. *Public Health Reports*, 123, 5, 555–566.
17. King, D. J. (2005) Humanitarian Knowledge Management. *Proceedings of the Second International ISCRAM Conference*, Brussels, Belgium, 1–6.
18. Kurasaki, K. S. (2000) Intercoder Reliability for Validating Conclusions Drawn from Open-Ended Interview Data. *Field Methods*, 12, 3, 1–17.
19. McDonald, S. (2016) Ebola: A Big Data Disaster, Privacy, Property, and the Law of Disaster Experimentation. *The CIS Papers*, 1-51.
20. Morton, M. and Levy, J. L. (2011) Challenges in Disaster Data Collection during Recent Disasters Opioid and substance abuse in teens identified from EMS Data View project EMS and Emerging Infectious Diseases View project. *Prehospital and Disaster Medicine*, 26, 3, 196–201.
21. OCHA. (2019) Information Management.
22. OCHA. (2002) Best Practices in Humanitarian Information Management and Exchange. *Symposium on Best Practices in Humanitarian Information Exchange*, Geneva, Switzerland, 1–6.
23. OCHA. (2018) Module: Humanitarian Information Management Training. Geneva, Switzerland.
24. Sphere Association. (2018) The Sphere Handbook | Humanitarian Charter and Minimum Standards in Humanitarian Response, Ed.4. *Sphere Association*, Geneva, Switzerland, 1-458.
25. Strauss, A. L. and Corbin, J. (1990) Basics of Qualitative Research: Grounded Theory Procedures and Techniques, Ed. 2. Sage Publications, Newbury Park, CA.
26. UNHCR. (2011) Guidelines for selective feeding: The management of malnutrition in emergencies. UNHCR, UN Refugee Agency and World Food Programme, Geneva, Switzerland,1-104.
27. University of Haiti. (2011) Haiti Humanitarian Aid Evaluation Structured Analysis Summary Report. New Orleans, LA, 1-35.

28. US Department of State. (2010) Haiti Earthquake: Breaking New Ground in the Humanitarian Information Landscape. Washington, D.C., 1-7.

29. Van de Walle, B. and Comes, T. (2015) On the Nature of Information Management in Complex and Natural Disasters. *Procedia Engineering*, 107, 403–411.

30. Van de Walle, B. and Dugdale, J. (2012) Information management and humanitarian relief coordination: findings from the Haiti earthquake response. *International Journal of Business Continuity and Risk Management*, 3, 4, 1-278.

31. Waugaman, A. and Fast, L. (2016) Fighting Ebola with Information: Learning from Data and Information Flows in the West Africa Ebola Response. Washington, D.C., 1-150.

32. WHO (2008). Managing WHO Humanitarian Response in the Field.

33. WHO (2009). A practical guide for country-level implementation of the Health Cluster Health Cluster Guide. 1-180.

34. Zhang, D., Zhou, L. and Nunamaker Jr, J. F. (2002) A Knowledge Management Framework for the Support of Decision Making in Humanitarian Assistance/Disaster Relief. *Knowledge and Information Systems*, 4, 3, 370–385.

35. Zhuang, J., Coles, J. B. and Yates, J. (2012) Case Study in Disaster Relief: A Descriptive Analysis of Agency Partnerships in the Aftermath of the January 12th, 2010 Haitian Earthquake. *Socio-Economic Planning Sciences*, 46, 67–77.

Community resilience towards disruptions in the payment system.

Peter Berggren
Linköping University
peter.berggren@liu.se

Molly Lundberg
Linköping University
mollu341@student.liu.se

Joeri van Laere
Skövde University
joeri.van.laere@his.se

Björn J E Johansson
Linköping University
bjorn.j.johansson@liu.se

ABSTRACT

This paper presents a study where nine Swedish citizens were interviewed about their concerns and expectations, from a customer perspective, in relation to a 10 day disruption in the payment system. The purpose of the study was to understand the customer's perspective in order to provide input to the development of a simulation environment. This simulation environment aims at allowing different stakeholders to experience how a disruption in the payment system affects the local community and thereby create understanding of how resilience is built and affected. The research questions were: What do customers expect to get access to? When? What are customers prepared for? How does this differ among different customer groups? The results indicate some understanding of how such a crisis affects the local community and what the informants expects to happen. The respondents represented a diversity of socio-economic backgrounds from rural and urban parts of the municipality.

Keywords

Community resilience, customer perspective, payment system, crisis management

INTRODUCTION

Disruptions in the payment system in societies where cash is no longer king may lead to dire consequences with unexpected cascading effects. In a society where many business owners have chosen to avoid cash payments, relying on credit cards or internet payment solutions (for example, Swish, Apple pay, Google pay, Paypal etc.) a disruption in the payment system lasting over several days will have unpredictable consequences. For example risks with interconnectedness of supply-chains, breakdown in the transport system due to lack of fuel for cars and trucks, social unrest and hoarding, failures in human handling of complex socio-technical system (Chopra & Sodhi, 2004; Reason, 1990; van Laere et al., 2017; Wears, Cook, & Perry, 2006).

The study is a part of the project Creating Collaborative Resilience Awareness, Analysis and Action for the Finance, Food and Fuel Systems in INteractive Games (CCRAAAFFFTING), commissioned by MSB (the Swedish Civil Contingencies Agency). Earlier papers from the CCRAAAFFFTING project have focused on different aspects of disruptions in the payment system and how to build a simulation environment for this (van Laere et al., 2017; Johansson, van Laere, & Berggren, 2018; 2017; Berggren, van Laere, & Johansson, 2018; Johansson et al., 2018; van Laere et al., 2018). This paper takes on the customer perspective. The study reported in this paper is based on a bachelor thesis (Lundberg, 2018). Within the CCRAAAFFFTING project, gaming-simulation is used to simulate this interconnected infrastructure in the payment system. Simulation generally aims at designing a model of a system in a complex problem area in order to perform various experiments (Grune-Yanoff & Weirich, 2010). The simulation approach used in CCRAAAFFFTING is described in detail in Johansson, Laere, and Berggren (2018). In short, the simulation comprise a number of grocery stores (ranging from local convenience stores to mega-stores), petrol stations, banks and the flows of goods, fuel, and payments (both cash and by other transfers) that occur between these. Gaming-simulation is used to gain deeper insight in the behaviour of the participants by evaluating various operating strategies against each other in one or multiple scenarios (Laere et al., 2006). It also creates a deeper learning opportunity since the participants are active

participants in the simulation and are not just passive observers.

Resilience is used to describe how a system critical to society, such as industry, infrastructure, finance or ecology, can absorb changes or disturbances and still persist (Holling, 1973; Foster, 1993). Community resilience is defined as a "process linking a set of networked adaptive capacities to a positive trajectory of functioning and adaptation in constituent populations after a disturbance" (Norris et al., 2008, p. 131). A community is defined as "an entity that has geographic boundaries and shared fate. Communities are composed of built, natural, social, and economic environments that influence one another in complex ways" (Norris et al., 2008, p.128). Community resilience is about the community´s ability to identify, summon, and address social problems and to use resources held by the community such as knowledge, skills, and systems to handle a disturbance. The customers are part of a community and can thus contribute to community resilience. A disturbance can be seen as a crisis, which might develop into a disaster. No matter if a disaster is natural or human-induced (Shaluf, Ahmadun, & Mat Said, 2003), it might affect the citizens access to cash. Parker (1992) suggested a definition of disaster as "an unusual natural or man-made event, including an event caused by failure of technological systems, which temporarily overwhelms the response capacity of human communities, groups of individuals or natural environments and which causes massive damage, economic loss, disruption, injury, and/or loss of life". Despite the effort to understand risks and develop routines for preventing and easing the effects of serious disruptions in the payment system in Sweden, there is still a lack of insight into how numerous actors in society (e.g. citizens, food stores, petrol stations, voluntary organizations, and so on) will act in case of a temporary or complete breakdown of the payment system (Johansson et al., 2018). Several key actors in the payment system have articulated that they will take a larger responsibility than their formal responsibility (MSB, 2009). How then, would the general public react to a prolonged disturbance in the payment system? More specifically:

How is the customer prepared for disruption in the payment system?

What does the customer expect to get/have access to?

When does the customer expect to get/have access?

How does this differ among different customer groups?

The answers to these questions will be used to inform the continued development of the simulation platform and scenarios for the CCRAAAFFFTING project. This will allow for a gaming-simulation, as the knowledge source is rooted in empirical findings. In addition, participants will feel more at ease relying on the stated behaviors of real customers.

METHOD

This was carried out as an interview study with different customer groups.

Participants

Nine persons volunteered to participate (5 women and 4 men). Their age varied between 23 to 76 years. The participants represented several different customer groups. All participants lived in a mid-sized Swedish municipality (> 100 000 inhabitants). They all were the primary provider of food for the household they belonged to (or shared the responsibility equally with another person). Two were students at the local university, one person was retired, and seven persons were employed. Six participants lived in or next to a larger city, one in a smaller town, and two were living in the countryside. Hence, the respondents represented a wide diversity of socio economic backgrounds and came from different parts of the municipality

All participants were informed about the study and gave informed consent to participating. No reimbursement was given. The study complies to ethical research regulations (Vetenskapsrådet, 2002) and the GDPR (the General Data Protection Regulation effective in EU). No ethical approval was necessary for this study according to Swedish law.

Material

A semi-structured interview approach was used (Howitt, 2013). Pre-identified questions were used, which were supplemented with questions that evolved during the interview. The pre-identified questions were identified through walk-throughs of identified payment disruption scenarios and piloted with persons who took the roles as customers when responding. The proper interviews were recorded and later transcribed. All interviews were held in Swedish.

Analysis

After the material had been transcribed, it was analyzed using thematic analysis. Thematic analysis is a method for identifying, analyzing, and reporting patterns in data (Braun & Clarke, 2006). Howitt (2013) states that thematic analysis is studying what is being said, rather than how it is said. Themes are found through an inductive approach, or using a bottom-up perspective, where the quality of statements in relation to the research questions is important (Braun & Clarke, 2006).

RESULTS

Four main themes were identified. These had ten sub-themes connected to them. The main themes and sub-themes can be seen in Table 1 (below).

Table 1. Themes and sub-themes identified using thematic analysis.

Main theme	Sub-theme	Comment
At home (A)		This theme is about the preparedness of the customers
	Having cash is random (A.1)	
	To manage 72 hours without shopping (A.2)	
When the crisis is present (B)		This theme focus on types of products the customers would look for and desired information
	Durable products (B.1)	
	The importance of information (B.2)	
When the debit cards does not work (C)		This theme focus on concerns regarding not being able to use bank cards
	Worry about cash machines running out of money (C.1)	
	Anticipations when cash runs out (C.2)	
	Alternative solutions to the problem (C.3)	
Who is responsible (D)		This theme is about expectations on how society and the community will react
	The responsibility of the stores (D.1)	
	The responsibility of the banks (D.2)	
	The responsibility of the government and the state (D.3)	

The first main theme *At home* (A) is about the preparedness of the customers. It includes the subthemes *Having cash is random* (A.1) and *To manage 72 hours without shopping* (A.2). *Having cash is random* (A.1) is about that many persons do not have any cash at home or in their wallet. The majority of the informants usually did not carry any cash, and if they had cash it was mostly from when other people had paid them cash. One informant explained that cash was from older relatives who had paid for something with cash or that the kids had cash to better understand how money works. *To manage 72 hours without shopping* (A.2) concerns if the informants would manage without shopping for 72 hours. All informants claimed that they would. However, people living inside the cities, close to grocery stores, said that that was about the limit of their food stored at home. Persons living further away from the grocery stores or outside the cities said that they would be able to cope for a longer time without shopping. They had a stock of food and fuel, and would be able to cope for up to

a week.

The second main theme *When the crisis is present* (B) focus on types of products the customers would look for and what information is desired. The first subtheme *Durable products* (B.1) emerged as a response to the question "If you know there was going to be a disruption in the payment system, what would you buy?". All informants said that they would buy durable basic products; eggs, canned food, milk powder etc. Only people living outside the cities would buy fuel. This subtheme points at that the customers are looking for durable products that are easy to stockpile so that they won't have to shop as often as they usually do. This demonstrates that a resilient behavior emerges as the crisis has already happened. *The importance of information* (B.2), the second subtheme, is about what information the informants think they need. A majority of the informants considered that information should be available through newspapers, internet, and television, while also on billboards outside shops. What information is needed differs, but they think that information about how to go about paying without bank cards is central.

When the debit or credit cards does not work (C) the third main theme focus on concerns regarding not being able to use bank cards. Three subthemes were identified: *Worry about cash machines running out of money* (C.1), *Anticipations when cash runs out* (C.2), and *Alternative solutions to the problem* (C.3). Under the subtheme *Worry about cash machines running out of money* (C.1) some informants would anticipate that cash machines would run out of cash and that the amount of cash in the Swedish society was not enough in relation to expected need. This could lead to higher rate of criminality and a "we against them" feeling. At the same time some informants did not think that there would be any problems with access to cash from cash machines. From the next subtheme *Anticipations when cash runs out* (C.2), in direct opposition to the previous subtheme, some informants thought that collaboration and support among the public would increase. People might car pool, use public transportation, or stay with friends (closer to work) to save fuel. One informant thought that trading possessions might be a way of getting around not being able to shop. *Alternative solutions to the problem* (C.3) was a subtheme where the informants stated different alternative solutions that they saw possible; use credit, invoice, ration cards, Swish (a Swedish digital system for exchanging money between users), or manual reading of bank cards.

The final main theme *Who is responsible* (D) is about expectations on how society and the community will react. Here, three subthemes become apparent. The subtheme *The responsibility of the stores* (D.1) involved that most informants considered that the stores had the major responsibility for resolving the situation. That is, some informants thought that the stores were to settle the issue with the payment system, while others considered that the store's responsibility was to set up a temporary solution for payment. Some informants expected the stores to close down during the payment disruption. Another subtheme was *The responsibility of the banks* (D.2). Here, the informants thought that the banks had a large part in handling the disruption, both in terms of resolving the actual cause of the disruption as well as expecting that the banks support society in providing cash and making offices and cash machines available through extended opening hours. *The responsibility of the government and the state* (D.3) concerned how the government and governmental agencies needed to step in and take control of a situation so that everyday life of individuals could continue.

DISCUSSION

This study aimed at answering the following questions:

- How is the customer prepared for a disruption in the payment system?
- What does the customer expect to get/have access to?
- When does the customer expect to get/have access?
- How does this differ among different customer groups?

This section will first present the answers to the research questions and then provide a general discussion.

How is the customer prepared for a disruption in the payment system?

Most informants were not prepared if the debit or credit cards stopped working. Few had any cash readily available, while some had food stocked lasting for up to more than a week. Most informants said that they could last 72 hours without shopping (a time frame that citizens are expected to cope without the government providing food in the event of a crisis; MSB, 2015).

What does the customer expect to get/have access to?

Expectations point in different directions; some informants hoped that the banks and stores could resolve the problem, others thought that cash would not be available as the cash machines would run out of cash. All informants anticipated information needs on the development and escalation of the crisis. The information should be accessible through usual information channels, be clear and concise, should focus on facts about the situation and how to act as citizens in order to not increase the crisis escalation. The informants foresaw that durable food products would be in demand, as it is easier to store and keep. However, informants in the cities expected that food would be accessible and available through shops as they did not have large stocks of food at home (more than 72 hours of food).

When does the customer expect to get/have access?

The 72-hours recommendation from authorities seemed to be a rule of thumb for informants' expectations. Hence, a longer crisis would burden community resilience to larger degree. Most informants would not manage a 10-day crisis without support from the authorities.

How does this differ among different customer groups?

Citizens living inside cities have expectations and preparedness that indicate a less resilient behavior, as they are less prepared with stored food and consumables with short turnover in their homes. They are used to visit the shop frequently next to their home to purchase products that they need. One reason might be since living in city centers, every square meter is more expensive. Hence, to keep costs down, less money is spent on storage space where durable food can be stored. Further, the fact that stores are available, usually within walking distance, decreases the need to stockpile food and other consumables. People in the cities are more dependable on food, while people outside the cities seem to have more need for fuel in order to be able to move around.

General discussion

The interviews suggest that people living in the countryside are more resilient than those who live in the city, in a situation where the payment systems stop working. People need more information about payment systems to be more resilient and to reduce concerns and social unease regarding what might happen. A disruption in the payment could lead to distrust in the payment system including the authorities and businesses responsible, even if it is just an expected responsibility. Welch et al., (2005) state that "trust makes market behavior possible by allowing people to exchange money, a scarce re-source, without great levels of risk or uncertainty being incurred" (p. 466). Declining trust in government leads to reduced support for government action (Chanley, Rudolph, & Rahn, 2000). The validity and authority of a democratic system becomes hollow when citizens withdraw support for government and become less willing to comply with governmental decisions. Brehm and Rahn (1997) showed a correlation between social trust and civic participation. Hence, a disruption in the payment could lead to distrust in the payment system causing lower levels of trust in the government and in lower levels of civic participation. This would decrease community resilience, the community´s ability to identify, summon, and address social problems and to use resources held by the community such as knowledge, skills, and systems to handle a disturbance. Such a decrease in community resilience could become a downward spiral into social disorder. From the sociological literature we assume "that stable social relationships cannot exist for long in the absence of social order. However, it is equally apparent that trust is a requirement for both social order and social relationships" (Welch et al., 2005, p. 467). This dependence on trust in social relations on the individual level have shown to affect and be transferred to group and community level (Welch et al., 2005).

Future work

Including citizens with different backgrounds would provide alternative experiences. For example, interviewing citizens/refugees who have fled from warzones could bring a different perspective on what is essential in times of crisis.

CONCLUSION

The themes identified in this interview study provides input to the larger CCRAAAFFFTING project in that they offer empirical findings as input to the gaming-simulation so that the realism is as truthful as possible, and that the injects and their effects in the simulation environment are authentic and reasonable. The current simulation utilizes an agent-based model, implemented in the AnyLogic™ platform. Customer agents shopping needs are modeled based on available statistics and assumptions. These agent-models can be altered to better reflect customer expectations during the disruption event. The findings from this study also suggest that the

community resilience and social trust can have a grand effect on the escalation and cascade effects initiated by a disruption in the payment system.

ACKNOWLEDGMENTS

This research was supported by Grant 2016-3046 of the Swedish Civil Contingencies Agency.

REFERENCES

Berggren, P., Laere, J. van, & Johansson, B. J. E. (2018) Using a mixed-methods assessment approach in a gaming-simulation environment to increase resilience In: *ECCE2018*. Utrecht, NL.

Braun, V. & Clarke, V. (2006) Using thematic analysis in psychology *Qualitative Research in Psychology*, **3**, 77–101.

Brehm, J. & Rahn, W. (1997) Individual-Level Evidence for the Causes and Consequences of Social Capital *American Journal of Political Science*, **41**, 999–1023.

Chanley, V. A., Rudolph, T. J., & Rahn, W. M. (2000) The Origins and Consequences of Public Trust in Government *Public Opinion Quarterly*, **64**, 239–256.

Chopra, S. & Sodhi, M. S. (2004) Managing Risk To Avoid Supply-Chain Breakdown *MIT SLOAN MANAGEMENT REVIEW*, 53–61.

Grüne-Yanoff, T. & Weirich, P. (2010) The Philosophy and Epistemology of Simulation: A Review. *Simulation & Gaming*, 41, 20–50.

Holling, C. S. (1973) Resilience and Stability of Ecological Systems *Annual Review of Ecology and Systematics*, 4, 1–23.

Howitt, D. (2013) *Introduction to Qualitative Methods in Psychology* 2nd ed. Pearson Education Limited, Gosport.

Johansson, B. J. E., Jaber, A., van Laere, J., & Berggren, P. (2018) The lack of preparedness for payment disruptions in local community core businesses In: *ISCRAM 2018*. Rochester, NY.

Johansson, B. J. E., van Laere, J., & Berggren, P. (2017) Using simulation games to assess critical infrastructure resilience in case of payment disruptions In: *Proceedings of the 7th Resilience Engineering Association (REA) International Symposium* pp. 1–7. Liege, Belgium.

Johansson, B. J. E., van Laere, J., & Berggren, P. (2018) Evaluating Team Resilience in Simulator-Based Crisis Management Training In: *ISCRAM 2018*. Rochester, NY.

Laere, J. van, Berggren, P., Gustavsson, P., … Wiberg, C. (2017) Challenges for critical infrastructure resilience: cascading effects of payment system disruptions In: *ISCRAM 2017* Vol. 2017–May. Albi, France.

Laere, J. van, Berggren, P., Ibrahim, O., Larsson, A., & Kallin, S. (2018) A simulation-game to explore collective critical infrastructure resilience In: *Safety and Reliability – Safe Societies in a Changing World: Proceedings of ESREL 2018*, S. Haugen, A. Barros, C. van Gulijk, T. Kongsvik, & J. Vinnem (eds.) pp. 1305–1312. CRC Press, Trondheim, Norway.

Laere, J. van, Vreede, G. J. de, & Sol, H. G. (2006) A social simulation game to explore future coordination in knowledge networks at the Amsterdam Police Force. *Production Planning and Control*, **17**, 558–568.

Lundberg, M. (2018) *What would you do if debit cards suddenly stopped working?: A qualitative study of costumers' anticipations when there are disruptions in the payment systems* (No. LIU-IDA/KOGVET-G--18/012--SE). Linköping. (Report in Swedish).

MSB (2015) *Resultatmål. Förslag till målstruktur och mål inom fem områden* (No. 2014–2378) Vol. 1. Stockholm.

MSB (2009) Faller en – faller då alla? Downloaded from https://www.msb.se/RibData/Filer/pdf/24573.pdf 2017-12-07.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008) Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness *American Journal of Community Psychology*, **41**, 127–150.

Parker, D. (1992) *The mismanagement of hazards - Hazard Management and Emergency Planning, Perspective on Britain*, James and James Science Publishers, London.

Reason, J. (1990) The Contribution of Latent Human Failures to the Breakdown of Complex Systems *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, **327**, 475–484.

Shaluf, I. M., Ahmadun, F., & Mat Said, A. (2003) A review of disaster and crisis *Disaster Prevention and Management: An International Journal*, **12**, 24–32.

Vetenskapsrådet (2002) *Forskningsetiska principer inom humanistisk-samhällsvetenskaplig forskning*.

Wears, R. L., Cook, R. I., & Perry, S. J. (2006) Automation, interaction, complexity, and failure: A case study *Reliability Engineering and System Safety*, **91**, 1494–1501.

Welch, M. R., Rivera, R. E. N., Conway, B. P., Yonkoski, J., Lupton, P. M., & Giancola, R. (2005) Determinants and Consequences of Social Trust *Sociological Inquiry*, **75**, 453–473.

Visualizing Early Warning Signs of Behavioral Crisis in Military Veterans: Empowering Peer Decision Support

Olawunmi George
Marquette University
olawunmi.george@marquette.edu

Rizwana Rizia
Marquette University
rrizia82@gmail.com

MD Fitrat Hossain
Marquette University
mdfitrat.hossain@marquette.edu

Nadiyah Johnson
Marquette University
nadiyah.johnson@marquette.edu

Carla Echeveste
Medical College of Wisconsin
cecheveste@mcw.edu

Jose Lizarraga Mazaba
Medical College of Wisconsin
jlizarraga@mcw.edu

Katinka Hooyer
Medical College of Wisconsin
khooyer@mcw.edu

Zeno Franco
Medical College of Wisconsin
zfranco@mcw.edu

Mark Flower
Dryhootch of America
markflower999@gmail.com

Sheikh Iqbal Ahamed
Marquette University
sheikh.ahamed@marquette.edu

Praveen Madiraju
Marquette University
praveen.madiraju@marquette.edu

Lisa Rein
Medical College of Wisconsin
lrein@mcw.edu

ABSTRACT

Several attempts have been made at creating mobile solutions for patients with mental disorders. A preemptive approach would definitely outdo a reactive one. This project seeks to ensure better crisis detection, by assigning patients (veterans) to caregivers (mentors). This is called the mentor-mentee approach. Enhanced with the use of mobile technology, veterans can stay connected in their daily lives to mentors, who have gone through the same traumatic experiences and have overcome them. A mobile application for communication between veterans and their mentors has been developed, which helps mentors get constant feedback from their mentees about their state of well-being. However, being able to make good deductions from the data given as feedback is of great importance. Under-representing or over-representing the data could be dangerously misleading. This paper

presents the design process in this project and the key things to note when designing a data visualization for timely crisis detection and decision-making.

Keywords

crisis, mental health, visualization, veterans, clinical decision.

INTRODUCTION

The process of moving from the days of active military service into living within the community of civilians could be very challenging for members of the military. It has been found out to be a major change in the life of veterans, since it affects almost every aspect of their lives (Elnitsky *et al.*, 2017). Their lifestyle, attitude, responsibilities have to change or be suitable for these areas of their lives, to avoid chaos, crisis or unpalatable situations. This shows how important re-integration is, as this can negatively impact various aspects of the veteran's life, such as the mental state of the veteran, leading to psychological issues and distress.
It has therefore been seen and recognized that there is the strong need to prepare veterans for reintegration as much, if not more, as they are prepared for deployment to war (Rizia, 2016).

Simple solutions sometimes are not adequate enough to solve crisis situations, due to the interconnected and interwoven nature of these crisis situations. There are certain similarities between dissimilar events such as natural disasters and mental health crises suffered by individuals. These similarities include: vulnerabilities created beforehand, warning signs that appear early enough, before the occurrence of the crisis or disaster, and a crisis event occurring beyond the critical point; for which efforts and resources must be employed in order to remedy any harm done and to bring things back to normalcy. Predicting true crisis events, using human or computational techniques have been quite difficult and not getting accurate predictions can lead to serious problems (Franco *et al.*, 2016).

Dryhootch (DH), a veteran-led community organization in Milwaukee has successfully implemented a veteran peer-mentor support program for helping veterans reintegrate into the society, which has been shown to be effective (Rizia *et al.*, 2014). A technological approach has also been put in place and is still currently being worked upon. The approach makes use of an online support system for the DH veterans, which has already been built and is in use. Also, a mobile technology-mediated peer-mentor support system called the Quick Reaction Force (QRF) application, which was carefully designed considering quite a number of factors, has been built and is now being deployed for use (Rizia *et al.,* 2015). Since detecting possible crisis events before they occur is of utmost importance here, the task of being able to visually present, in the best possible way, any data collected from veterans to their peer mentors must be solved. A solution to the stated problem would allow for better predictions and detections of possible crises. Presented here is a design solution for the representation of data, on the state of well-being of veterans, giving a visually-aided clinical decision support system.

The Use of Mobile Technology in Behavioral Medicine

Mobile technology use in healthcare has seen significant growth and has been proven to be a very good choice in the development of healthcare solutions. Free *et al.*(2013) conducted a review to assess the effectiveness of mobile technology solutions provided to healthcare consumers. Healthcare providers need to effectively encourage their patients to make healthy lifestyle choices, which can help combat their diseases. Traditional face-to-face consultations are limited, but mobile technologies such as mobile phones help to achieve the desired effectiveness in the delivery of health messages for behavioural situations.

It was demonstrated that mobile interventions through text-messaging increased adherence to the therapy administered, albeit applied to a niche of smokers (Free *et al.*, 2013) and adolescents with chronic health conditions (Badawy *et al.,* 2017). Also, Santosh *et al*. (2009) conducted a similar review, geared towards evaluating the role of cell phones and text messaging interventions in improving health outcomes and processes of care for health conditions such as diabetes. Their findings concluded that enhancing standard care with reminders, disease monitoring and management, and education through cell phone, voice, and short message service could help improve health outcomes and care processes.

Informatics Approaches to Clinical Decision Support

Clinical decision support systems (CDSSs) help caregivers make appropriate clinical decisions. CDSSs have been adopted by both professional and paraprofessional caregivers. A review was done on how well CDSSs affect physicians' performance. The use of CDSSs, by medical professional caregivers, to recommend proper medicine doses, diagnose chest pain or send notifications for immunizations were examined and the findings showed that given the use of CDSSs, physician performance can be improved (Johnston *et al.*, 1994). CDSSs have been proposed as the solution to overcoming the significant barriers, which exist and are hindering the effective and efficient application of genetics at the point of care. Incorporating CDSSs is seen as a practicable solution to help clinicians manage the complexities of genetics at the point of care (Welch and Kawamoto, 2013). In different countries, paraprofessionals like skilled nurses use clinical decision support software for tele-health (Russell *et al.*, 2017).

Various studies show that visualization tools positively impact clinical decision support and increase practitioners' performance. Visualization tools assist in clinical decisions in infection management (Garcia-Caballero *et al.*, 2015). In another study related to child health improvement, with the use of an electronic medical record platform, utilizing 170 unique variables representing unique clinical observations, in 300 medical logic modules, the use of visualization tools allowed for more effective interaction of different teams (Liu *et al.*, 2015). Mane *et al.* (2011) mentioned how the use of visual analytics can play a significant role in making clinical evaluations and understanding the effectiveness and risk of different therapeutic options for different subpopulations of patients. It is believed in Mohr *et al.* (2013) that data visualization approaches are necessary for making effective clinical decisions via mobile technologies in mental health, rather than the use of mobile technologies without data visualization. It is believed that data visualization approaches are necessary for making effective clinical decisions via mobile technologies in mental health. In this paper, we address this issue with respect to veterans' mental health and paraprofessional decision-making for early crisis detection.

Essentializing Early Warning and Crisis Information for Paraprofessional Caregivers

Assessments of change, dynamics, and cause-and-effect are at the heart of thinking and explanation. To understand is to know what cause provokes what effect, by what means and at what rate. Representation of such knowledge is also vital. A carefully thought-up design strategy must be in place to ensure the proper arrangement in space and time of images, words and numbers. Tufte (1997, p.9) suggests that clarity and excellence in thinking is a parallel to clarity and excellence in the display of data.

In any data representation and visualization endeavour, the principles that inform the design for the representation of the data involved are very important. Questions such as, "What principles should inform the designs for showing the data?", "Where do the principles come from?", "How can the integrity of quantitative descriptions be maintained?" and "What are the standards for evaluating visual evidence, used for making decisions?", need to be asked (Tufte, 1997). Caroll e*t al.* (2014) conducted a systematic review focused on the landscape of infectious disease visualization tools for public health professionals. This would clearly impact the decision to be made based by them, given the varying choices of data visualization tools. Their objectives included identifying public health user needs and preferences for infectious disease information visualization tools. The first visualization used in the study was a dot map to represent each incidence; the second visualization used a choropleth map to represent data on an individual level. The map showed the incidence rate per 100,000 persons and this further showed differences. Graded colours were used to indicate the values of some aggregate measure in specified areas, that is, telling the disease incidence rate based on the colour intensity. A darker colour was an indication of a higher rate of incidence. Also, individual or aggregate level data could be used to derive a spatial risk gradient. The possibility of using an individual or aggregate level data to statistically derive a spatial risk gradient was also demonstrated (Carroll *et al.*, 2014). These three visualization techniques made use of the same data, but different approaches to visualizing the data, at hand. The third showed the information in a much more condensed and useful manner, with a risk gradient depicted, making it much more helpful, as compared to the second, which showed the concentration of the incidences only and the first which merely showed each individual occurrence, without a good decision support framework.

Prior Work

This work builds upon and is an enhancement to an existing work. The team has an ongoing work, namely the Quick Reaction Force (QRF) mobile application, which has been centered around the design and implementation of a mobile solution, which harnesses a peer-mentor model for monitoring, communicating and mentoring younger veterans by older ones (Rizia *et al.,* 2015). Over time, there have always been attempts to build an improved solution to the existing mobile application and this explains one such improvement made. All efforts or work described here have received Institutional Review Board (IRB) approval for human subjects research.

Veteran Community Engagement for Research

This work is driven from a Community Based Participatory Research (CBPR) perspective, Dryhootch leaders and faculty from the Milwaukee Veteran Affairs (VA) Medical Center and the Medical College of Wisconsin. We have partnered with Dryhootch of America, a non-profit veteran-led, veteran-serving community organization headquartered in Milwaukee, Wisconsin for about 5 years to develop a smartphone app to support veteran-to-veteran mental health intervention. Descriptions of this community-academic partnership, the Dryhootch Partnership for Veteran Health, its formation, and lessons learnt are detailed elsewhere (Franco, Logan et al. 2016). One common area of interest within the partnership was improving outreach to younger veterans returning from Operation Enduring Freedom (Afghanistan) and Operation Iraqi Freedom (often referred to as "OEF/OIF veterans") using technology. OEF/OIF veterans have different expectations about connecting with systems of care often preferring technology-mediated contact as compared to veterans from prior US military service eras (Franco *et al.*, 2018).

METHOD

The QRF system is one that requires that veterans' data, collected in form of feedback, be appropriately represented, due to the reason that an early detection of crisis warning signals is paramount to the success of the peer mentorship program. This can only be achieved if the information is presented to the mentors in the appropriate way. With the right data representation, a mentor can easily detect, with the visual cues, what the state of the veteran is and can notice early any signs that may indicate a potential crisis.

This work makes use of a collaborative design approach, by engaging the stakeholders in the design of a key part of the mentor view of the mobile application, which involves giving a mentor the necessary information needed to make a decision on the state of his mentee. Throughout the design of the application, there were inputs from the veterans as to what would be good to have, with the more important and essential ones taking top priority. For this aspect, however, a broader coverage of veteran mentors were involved in deciding the appropriate parameters to be used. This obviously made the design path clearer and strengthened the acceptability of the application to its users. From the veteran view of the application, the veterans are presented weekly surveys, which they fill. The survey consists of five questions, which are centered around their current state of physical and mental health and can be taken at any time in a day. Some of the questions asked are:

a. Have you engaged in any risky behavior (as you define it) this week?
b. Has your health changed this week?

All questions have only three options: Yes (a score of 3), Maybe (a score of 2) and No (a score of 1). This was made simple due to the veterans' preference that options be simpler than a typical 5-point research study scale. With these, the scores are assigned based on the responses for each question and an aggregate of these is the final score of the veteran.

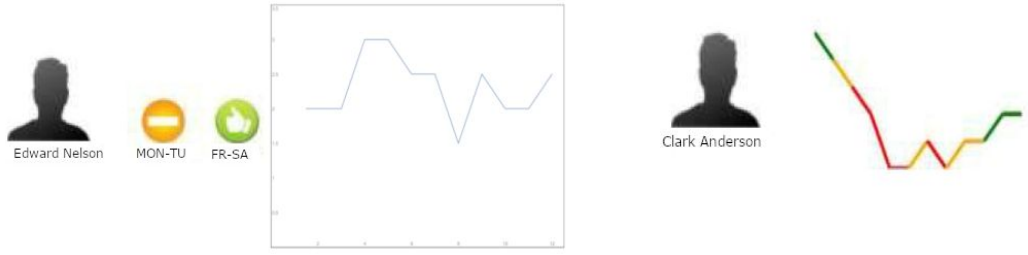
For instance, if the responses to the questions included 3 "Yes" responses, 1 "No" and 1 "Maybe", the total score for the veteran would be 12 out of 15. Every time that the veteran takes the survey, this score is calculated. In essence, if a veteran had better responses throughout the survey, he garnered a score of 15; if worse responses were given, he got a score of 5 and if mixed responses, he got a cumulative score based on the response scores. If the veteran missed the survey, a score of zero was given to represent that the survey was missed.
These scores are reported to their mentors, by virtue of a graph representation. Since the scores are indicative of whether the veteran is performing well and is in a good state, there is the need to adequately show the state of a veteran over a period of time. The chosen period to be displayed to the mentor was the last seven (7) days from

the current day. That is, for every day, over the last seven days, the state of the veteran is shown, with visual aesthetics that can adequately portray the needed information to the mentor.
There were a number of different approaches tried, in a bid to get a visualization that best explains the state of the veteran. In all of these approaches, certain things were observed, learned, and adjusted upon for a better visualization. These approaches are discussed here and the key points to note from each trial approach and its outcomes are stated, as well. After utilizing different approaches, the approach that was finally adopted and taken was one that involved the input of the mentor veterans. With reference to the earlier design specification, Rizia (2016, p.54) states the tasks that need to be performed by a mentor, once the dashboard showing his assigned veterans is displayed. The tasks include:

a. Detecting early warning signs of crisis.
b. Determining if there is an immediate need to reach out to particular veterans who are in an acute mental health situation.
c. Make a decision about how to best use limited resources.

The initial design approach, prior to this, involved creating three different levels of mock screens for the mentee panel User Interface (UI). This was moved from a UI with maximum information availability (one having a trend indicator icon and a monochromatic graphical display) towards a UI that was fully essentialized (one without a trend indicator icon and a coloured graphical display) with minimal elements. The UI levels were defined by the researchers and the UI in the latest application version was taken as a reference and improved upon. For three of the UI levels, only the UI representation changed. All other information such as survey scores and veteran information were the same (Rizia, 2016).

The icons were a thumb-down, a thumb-up or a neutral sign. A thumb-up indicated an improvement from the past response, a thumb-down indicated a declination from the past response and a neutral sign represented no change or very little change. A graph was also displayed for each veteran and the graph values were the scores of the veteran, based on the responses to the weekly surveys, filled over the past twelve weeks in a prior completed survey (Rizia, 2016).



(a) **(b)**

Figure 1. (a) Mock Screen for Maximum Information UI; (b) Fully Essentialized Mentee Panel UI

This approach made use of community-based feedback, by seeking responses from the veterans, specifically about which UI level best appealed to them. The conclusion was to implement a fully essentialized UI.

Also, prior to the implementation of a mobile application, a twelve-week survey was conducted, which involved recruiting veterans for a study over the stated period. The aim of the study was to assess the effectiveness and impact of a 12-week veteran peer mentorship program on the wellbeing of the veterans. This was done by assessing the veterans' PCL-5 scores at the entry into the program, mid-point and at the discharge from the program. The veterans were asked the questions stated above on a weekly basis and their responses were analyzed afterwards. The next figure shows the result of statistical analyses carried out to determine the Post Traumatic Stress Disorder Checklist (PCL-5) score of each veteran, who participated in the survey, over the 12-week period. This kind of information on the veterans is what needs to be meaningfully visualized to the mentors, with the use of a mobile application, for early crisis detection and decision-making. The bars representing each of the twelve weeks are coloured red for a worse state; yellow for the same state showing no difference in state as compared to the previous week; green for a better state or white for a missed survey. For the analysis shown below, 272 veterans' data was considered, with 129 of them having a PCL-5 score less than 33 and 143 having a score of 33 or more at entry into the program. The majority of participants in the survey

were younger veterans, who served during the Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) era.

Veteran Mentor Experience

It's imperative to understand the experience of the Veteran mentor. Their experience highlights the effectiveness of the design and also emphasizes the opportunities for future features. We know that Veteran mentors have the most contact with veteran mentees in comparison to psychologists or psychiatrists, or other professional healthcare providers. The veteran mentor forms a close relationship with their mentee, which fosters trust allowing for mentees to feel comfortable disclosing critical information to their peer mentor. This allows the veteran mentor to gain greater insight to the daily life, warning signs and high risk environments that are specific to their mentee.

Veteran mentors have shared that these insights help them to guide their mentee toward the mentee's own view of what well being means to them, which can be useful when the veteran is interpreting the data on the mobile application. However veteran mentors sometimes struggle with memory and attention. Any recall bias can be combated by the overview of the weekly trend line displayed in the application, which is an accurate representation of the mentee's status.

Veteran Mentors' Implicit Theories of Early Warning Signs and Crisis Events

In determining what constitutes an early warning sign or a precursor to a crisis event occurring with a veteran, an intuitive decision-making approach is taken. This approach involves checking the survey responses from the veteran for the presence of two worse responses in one week. This can serve as a symptom or an early warning sign of a crisis. Also, three or more worse symptoms in one week or more than two worse symptoms over two consecutive weeks could be considered as acute crisis. Unchanged PTSD symptoms or becoming worse at the twelve-week discharge could be considered a long-term crisis.This information would need to be represented to each mentor on a daily basis, for quick and effective decision-making. In Figure 2, the result of statistical analysis necessary to make these intuitive decisions were shown for both veterans who were initially identified as having PTSD and those who were not.

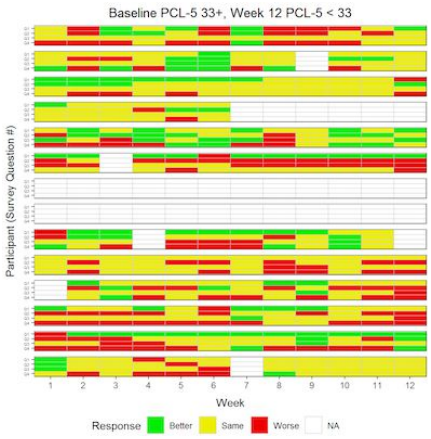


Figure 2. Representation of statistical findings from the 12-week survey data

Presented below is a figure showing the resulting visualizations for all approaches detailed here.

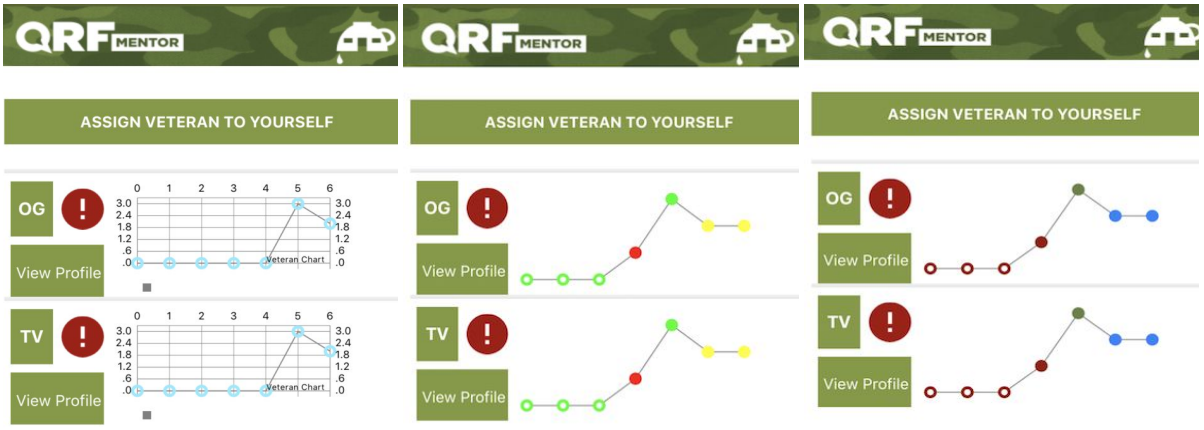


Figure 3. (a) Plotting Raw Scores; (b) Plotting an Abstraction of Scores; (c) Community-based Involvement

Plotting Raw Scores

The first approach was to plot the exact raw scores of the veteran against each day of the week to be shown on the sparkline. This showed the detail of the scores for each day, which seemed good and exact, but the graph plotted was quite rough, as the different scores shown, were without any other visual cue. All of the background lines of the graph were shown and this made it visually cumbersome. Also, the axes were labelled and considering the limitation of space in a mobile device, there needed to be more work done on the visualization to make it better fit for the representation intended. From Figure 3(a) above, the scores are plotted with no clear distinction as to what state the veteran might be in. The generic light-blue colour says nothing more and is simply a graphical decoration. Also, the presence of lines in the graph make it cluttered. That said, the veteran mentor would not be able to deduce vital concrete information, in good time in order to make the necessary intervention.

Plotting an Abstraction of Scores

Considering the inadequacies of the first visualization, a mock-up was designed for the visualization, with different options for the look of the sparkline. An option that eliminated the noise caused by lines and numbers was chosen. Also, there was the addition of visual cues, such as colours to represent each state of the veteran, as opposed to a general colour, which gave no additional information about the data being displayed. The colours green, yellow and red were used to denote good, fair and bad states, respectively. For empty points, a green circle with an empty hole within it was used. This approach involves plotting the raw scores of the veteran for each day with colours to give an impression of the state of the veteran. This was good but there were still subtle issues with it. As stated earlier, the initial approach showed the raw score with a general colour, to indicate the state of the veteran. However, this was not so helpful because of the lack of distinction between the colours. Also, the raw scores allowed for subjective interpretation. This was deemed a design flaw, as the technology and system should be designed to present the mentor with accurate and most vital information. What was done next was to abstract the scores data to the different levels: good, same, and bad. So, rather than have scores 1-15 being returned when the scores are fetched, a score of 0, 1, 2 or 3 was returned. The abstraction was done such that 0 was used to represent missing data, 1 was to represent a poor state, 2 to represent same state and 3 for a better state. Table 1 shows the categories and their colour representation.

SCORE	ABSTRACTION	COLOUR
Missing data	0	Green outline with empty circle
5-7.5	1	Red circle fully-filled.
7.5-12.5	2	Yellow circle fully-filled.
12.5-15	3	Green circle fully-filled.

Table 1. Table of Scores Abstraction

With this, only four possible values were returned and these were used for the sparkline. This approach was good for the following reasons:

1. The scores were more succinctly represented by state values and so, not all the scores, which might be too much information, were presented to the mentor.
2. The introduction of colours for the different abstractions changed the generic light-blue colour initially used, giving a more specific representation.

After these different options were chosen, another look was presented, as seen in Figure 3(b). Initially, a green outline and empty circle was used to indicate a missed survey. After careful consideration, the initial green outline with an empty circle was seen as misleading, as it was concluded that mentors might think, based on intuition that the veteran was doing well, without actually realizing that the survey was missed. This was due to the use of the green colour in the outline, which is more closely associated with a stable state of rest, growth and flourishing (Grant, 1879), with no perceived sense of danger or urgency, as opposed to the intent here. A missed survey might constitute a warning signal. However a veteran stated, during the deliberation, that if he were viewing the sparkline in a hurry, it might be easy to overlook the empty circle and assume a good state. Since the intent was to communicate to the mentor that the veteran missed the survey for the day, a green coloured outline was inappropriate for the intent because this could lead to a misinterpretation of the data. After deliberation, it was decided that the colour needed to be changed and replaced with one depicting a sense of urgency or possibly immediate danger. Obviously, the colour "red" would be a good fit for the situation.

Also, noted in the visualization arrived at after the second approach, the same state of the veteran, being represented by the yellow colour was seen to be quite inappropriate for the following reasons:

1. The yellow colour was too light, quite inconspicuous on the device and could be easily overlooked in an environment of high light intensity. Moreso, visually-impaired mentors could dismiss it.
2. The colour, though known to represent a warning sign (as in the case of traffic lights and other alerting systems), was still not seen as the best fit for the "same" state representation.

It was therefore arrived at that both the green outline for denoting missed surveys and the yellow colour for denoting "same" state had to be changed to colours more appropriate for communicating the intended state. With this, a third approach was decided upon. This approach was a community-based approach in getting a more appropriate visualization, based on the opinion of the community of veteran mentors.

Community-based Involvement

This last approach built upon the second approach, modifying the visual cues, based on a survey carried out that engaged the veteran mentors, who would be using the mobile application. The colour representation for a missed survey was changed to a red outline with an empty circle, instead of the previous possibly misleading green outline with an empty circle. Also, the colour for the same state was changed to blue, based on the veteran community input.

SCORE	ABSTRACTION	COLOUR
Missing data	0	Red outline with empty circle
5-7.5	1	Red circle fully-filled.
7.5-12.5	2	Blue circle fully-filled.
12.5-15	3	Green circle fully-filled.

Table 2. Table of Modified Scores Abstraction

The survey contained questions about which colour was preferable for a neutral state. Choices presented included yellow and blue. More responses were in favour of the blue colour, which was originally suggested by the expert anthropologist on the team. Also, the respondents (mentors) were presented with choices of shades of the blue and yellow colours preferable for the state. In addition, the respondents were presented with choices of shades of red and asked their preferences for the representation of the bad and missing states.

In general, the responses tended towards the use of the darker shades of colours and these were applied to the application. The resulting sparkline is presented in Figure 3(c). This was the finally agreed-upon visualization for the veteran data on the mentor view of the application. The focus was on designing and implementing an appropriate visualization for data regarding veteran health, which may be generalized to clinical decision systems. This was in line with a design effect mentioned in Febretti *et al.* (2014), which states how mutual reinforcement of grouped CDSS features can affect a caregiver's acceptance of care suggestions. Also stated is the positive effect of increasing the number of caregivers, if the designed interface steers users towards relevant features.

From the presentation, it is seen that the mentors can take decisions, without being burdened by information overload. They also do not have to make many assumptions or fill in many gaps for lack of information. The colors used were widely known colors that depict a particular information or emotion and these served as an enhancement to make decision-making easier and faster, as based on intuition, the mentors know the meaning of those colours.

CONCLUSION

The design of any clinical decision support system must be well thought-out and implemented. The employment of informatics approaches in building solid clinical decision support systems makes it much more effective and if well-designed provides a much greater impact on care administration efficiency, decision-making for crisis situations and patient results in terms of response to care administered and health status.
In the design of any system, relying upon the visualization of data for decision-making, the visualization tool used to represent a particular set of data may make or mar the progress of the decision system. As Tufte (1997) has stated, the key questions on the principles for the design have to be asked and answered, before an appropriate visualization tool or technique is used. It is therefore imperative to understand the data, the persons from whom the data are collected, the cause and effect relationship in the data and to provide the right tool for the data representation.

The work presented here, which is a portion of an on-going project with different phases of achievement, shows the importance of data visualization for decision making in crisis situations. We presented the path taken and noted key design elements involved in creating a data visualization component for timely crisis detection and decision-making. With reference to the design of the mobile application stated, several factors were considered: the combat-dressed figure in the welcome screen, the application menu bar army-green colour, the title of the application and other application components were selected to portray a military style. The words used in the

application were also purposefully selected in order to appeal to the army veterans and to make the system more welcoming to use. All of these choices took into consideration the trust issues the patients had with power authorities and persons of higher hierarchies. The system was designed outside of any elements that could conflict with the patients' perceived sense of security and trust and that could deter their effective use of the system. All these in addition to the subtle, but necessary details in the visualization of the patients' data had to be attended to and these would be further carried on in phases to come.
In future phases, enhancements to the application such as intervention tracking could be incorporated. With this enhancement, any interventions made by the paraprofessional caregiver could be tracked from the system. Then, the effect of the intervention could be measured over time, by observing how the patient's health state varies, based on the health scores after the intervention. Further modifications to the visual presentation might also be necessary for quick conveyance of vital information about the patient.

ACKNOWLEDGEMENT

The project described was supported by the National Center for Advancing Translational Sciences, National Institutes of Health, Award Number UL1TR001436. The content is solely the responsibility of the author(s) and does not necessarily represent the official views of the NIH. In addition, this project was partially funded by the Healthier Wisconsin Partnership Program, a component of the Advancing a Healthier Wisconsin endowment at the Medical College of Wisconsin.

REFERENCES

1. Badawy, S. M., Barrera, L., Sinno, M. G., Kaviany, S., O'Dwyer, L. C., & Kuhns, L. M. (2017). Text Messaging and Mobile Phone Apps as Interventions to Improve Adherence in Adolescents With Chronic Health Conditions: A Systematic Review. JMIR mHealth and uHealth, 5(5), e66. doi:10.2196/mhealth.7798

2. Carroll, L.N., Au, A.P., Detwiler, L.T., Fu, T.C., Painter, I.S., Abernethy, N.F., (2014). Visualization and analytics tools for infectious disease epidemiology: a systematic review. J. Biomed. Inf. 51, 287–298.

3. Elnitsky, C. A., Fisher, M. P., & Blevins, C. L. (2017). Military Service Member and Veteran Reintegration: A Conceptual Analysis, Unified Definition, and Key Domains. Frontiers in psychology, 8, 369. doi:10.3389/fpsyg.2017.00369.

4. Febretti, A., Stifter, J., Keenan, G. M., Lopez, K. D., Johnson, A., & Wilkie, D. J. (2014). Evaluating a Clinical Decision Support Interface for End-of-Life Nurse Care. Extended abstracts on Human factors in computing systems. CHI Conference, 2014, 1633-1638.

5. Franco, Z., et al. (2016). "Crisis Warning Signs in mHealth for Military Veterans: A Collaborative Design Approach." Proceedings of ISCRAM2016 Conference, Rio de Janiero, Brazil.

6. Franco, Z., et al. (2018). "Detecting & Visualizing Crisis Events in Human Systems: an mHealth Approach with High Risk Veterans." Proceedings of ISCRAM 2018 Conference, Rochester, New York, USA.

7. Free C, Phillips G, Galli L, Watson L, Felix L, et al. (2013). The Effectiveness of Mobile-Health Technology-Based Health Behaviour Change or Disease Management Interventions for Health Care Consumers: A Systematic Review. PLOS Medicine 10(1): e1001362. https://doi.org/10.1371/journal.pmed.1001362

8. Garcia-Caballero, H., Campos, M., Juarez, J. M., & Palacios, F. (2015). Visualization in clinical decision support system for antibiotic treatment. In *Actas de la XVI Conferencia de la Asociación Española para la Inteligencia Artificial, CAEPIA*(pp. 9-12).

9. Grant, Allen (1879). The Colour-sense: Its Origin and Development. An Essay in Comparative Psychology. Retrieved from https://play.google.com/books/reader?id=3bURAAAAYAAJ.

10. Johnston, M. E., Langton, K. B., Haynes, R. B., & Mathieu, A. (1994). Effects of computer-based clinical decision support systems on clinician performance and patient outcome: a critical appraisal of research. *Annals of internal medicine*, *120*(2), 135-142.

11. Liu, G. C., Odell, J. D., Whipple, E. C., Ralston, R., Carroll, A. E., & Downs, S. M. (2015). Data visualization for truth maintenance in clinical decision support systems. *International Journal of Pediatrics and Adolescent Medicine*, *2*(2), 64-69.

12. Mane, K. K., Bizon, C., Schmitt, C., Owen, P., Burchett, B., Pietrobon, R., & Gersing, K. (2012). VisualDecisionLinc: A visual analytics approach for comparative effectiveness-based clinical decision support in psychiatry. *Journal of Biomedical Informatics*, *45*(1), 101-106.

13. Mohr, D. C., Burns, M. N., Schueller, S. M., Clarke, G., & Klinkman, M. (2013). Behavioral intervention technologies: evidence review and recommendations for future research in mental health. *General hospital psychiatry*, *35*(4), 332-338.

14. Rizia, R., et al. (2014). "Mobile peer-mentoring: An approach to make veterans seek mental health-care support a normality." Proceedings of 10th IEEE International Conference on Collaborative Computing: Networking, Applications and Worksharing 2014 Conference, Florida, USA.

15. Rizia, R., et al. (2015). "Collaborative Design with Veterans: Identifying challenges of designing mhealth solution for veterans." Proceedings of the 17th International Conference on E-health Networking, Application & Services (HealthCom) 2015 Conference, Massachusetts, USA.

16. Rizia, Rizwana, "A Mobile Health Approach to Assist Veterans Reintegrating into Civilian Life" (2016). Dissertations (2009 -). Paper 633. http://epublications.marquette.edu/dissertations_mu/633

17. Russell, B., Smith, C., Valsecchi, R., & Andersson Bäck, M. (2017). System, society and dominance effects in the adoption of telehealth: A tri-country comparison. *Economic and Industrial Democracy*, *38*(3), 425-447.

18. Santosh Krishna, Suzanne Austin Boren, and E. Andrew Balas (2009).Telemedicine and e-Health.Apr 2009. Ahead of print. http://doi.org/10.1089/tmj.2008.0099

19. Tufte, Edwards (1997). Visual Explanations. Cheshire: Graphics Press, 1997. Print.

20. Welch, B. M., & Kawamoto, K. (2013). The need for clinical decision support integrated with the electronic health record for the clinical application of whole genome sequencing information. *Journal of personalized medicine*, *3*(4), 306-325.

Designing Disaster Information Management Systems 2.0: Connecting communities and responders

Kenny Meesters
Delft University of Technology
k.j.m.g.meesters@tudelft.nl

Vittorio Nespeca
Delft University of Technology
V.Nespeca@tudelft.nl

Tina Comes
Delft University of Technology
T.Comes@tudelft.nl

ABSTRACT

Information and supporting information systems is a key element in an effective emergency response. From creating situational awareness to informed decision making, information enables responders to optimize their decisions and operations. Today, with the increased availability of information technology around the globe, a new active player in the field of information management is emerging as communities are becoming increasingly active in the field of information gathering, analyzing and sharing.

However, communities may have specific requirements and approaches to using information systems in crisis situations. Moreover, connecting information systems between communities and responder pose specific challenges due to the different information needs, capacities and incentives to use them. In this paper we build on the DERMIS premises and explore through a case study if and how these principles apply to inclusive information systems. We present the initial findings of this work of designing information systems involving both communities and formal responders.

Keywords

Information Systems, Community Engagement, Participatory Systems, Systems Design, Inclusive Systems

INTRODUCTION

It has long been recognized that information plays a pivotal role in the response to disasters (Comfort et al. 2004; IFRC 2005). Information and communication technologies have fundamentally changed the availability and exchange of information before, during and after a crisis. Since the Haiti earthquake marked the beginning of disaster relief 2.0 (Crowley et al. 2010), there is a surge in information systems specifically designed for disasters (Neef et al. 2014; Piccolo et al. 2018; Streefkerk et al. 2014). Equally prominent is the use of platforms such as Twitter, Facebook, WhatsApp and other social media and instant messaging systems during disasters. In recent events, such as the Sulawesi earthquake/tsunami in Indonesia and the 2015 Nepal earthquake (Basu et al. 2017), WhatsApp was extensively used by both responders and the affected communities. In these and other disasters, WhatsApp became a critical information sharing platform in which a plethora of groups were formed for various coordination groups (Debnath et al. 2016; Meesters 2014; Sebastian et al. 2017).

The increased availability of information and the expanded reach of information networks bring about new challenges: information is gathered and shared across a wider network, a more diverse audience, and with more speed than ever before (Comfort et al. 2004; Gralla et al. 2013). As such, the requirements for systems that support effective information management also change. For example, systems need operate in a more distributed manner, allowing different user(groups) to connect, share and use information (Baharmand et al. 2016; Nespeca et al.). In addition, communities and individuals play a more prominent role. While these groups have long been recognized as the pivotal in effective disaster response (Twigg 1999; Weiss 1999), the increased profusion of mobile technology, digital literacy, and accessibility of ICTs have also opened up opportunities for them to directly engage in information processes (Comes 2016c; Harbers et al. 2014; Meier 2014; Munro 2012; Okolloh 2009).

All the more it is important that information systems in the Disaster 2.0 era are designed to provide the right information, at the right time to the right person. Turoff, Cumer and Van de Walle in their seminal paper "The design of a dynamic emergency response management information system (DERMIS)" examine requirements and design principles for information systems to be used during crisis response and emergency management

(Turoff et al. 2004). The DERMIS principles and premises have provided an important frame of reference for both the design of information systems themselves, as well as for the academic studies around those systems.

The focus of these design premises is on information systems used by formal emergency responders operating in an official or mandated capacity. Premises such as the 'need for training' or 'free exchange of information' are based on the analysis of information systems and processes in use by organizations and individuals with a formal role in the crisis management operations. In short, the scope of the DERMIS premises are the emergency response systems that are being designed, established and used by responding organizations.

The above-mentioned trends of the increasingly active role of communities in the information management during crisis response along the emergence of various day-to-day communication platforms show a fundamental shift in the design and use of information systems in crisis response. As information systems open up, 'common' applications are being used, and new actors enter the information eco-system, a re-examination of the DERMIS design premises is warranted.

In this paper we present the findings of an exploratory field study on today's use of information and information systems in crisis response and disaster management. The aim of this research is to uncover the explicit and implicit requirements of inclusive information system. Using the DERMIS premises for information systems design as an analytical lens, we examine how these premises manifest themselves in information systems with active participation of communities in the gathering, analyses and sharing of information during crisis response.

In the remainder of this paper we outline the methodology used, specifically focusing on our approach to revise the requirements and premises laid out in DERMIS to include community groups. Subsequently, we present a revision of the DERMIS principles to include the role of communities based on literature and interviews. Subsequently, we test and revise these adopted premises using a qualitative case study approach.

RESERCH APPROACH

This study combines theoretical and empirical work, as highlighted in Figure 1. The starting point was the development of a theoretical framework by mapping the DERMIS principles against the requirements brought about by the wide diffusion of ICT. These requirements were elicited through a literature review as well as through interviews with professional responders and digital volunteers. From there, we designed a first set of principles.

In a second step, we tested and revised the new principles in a field research case study in Jakarta / Indonesia. The study area was chosen because the population is frequently exposed to floods and crises. At the same time, there are active local communities that use digital tools to self-organize and improve their resilience, for example through community driven risk mapping or self-designed disaster preparedness measures. Our interviewees were selected to be representative for the main actors (communities, NGOs and public authorities). Throughout the field work 70 respondents were reached through 11 interviews, 2 focus groups and 3 workshops.

To focus on key drivers of change since the original DERMIS principles were published, we rooted our research in theories of coordination; information sharing; decision-making and resilience. The interviews aimed at investigating three main points: situations faced, and decisions made, information management (collecting, analysis and sharing), and the tools used to facilitate information exchange and communication. In combination with this semi-structured approach, we included open questions in an exploratory approach to investigate the priorities and requirements that of the actors identified based on their own experience with disasters. All details of the approach and interview guidelines are documented in the Deliverable 2.1 of the European Project COMRADES[1]. This interview protocol is centered around decisions and decision making processes, the use of information in these processes, and the information tools and methods to obtain and share this information (Lipshitz et al. 2001). To complement this approach for eliciting requirements for new technologies, we also used an Ushahdi-based[2] instance for crowd sourcing to demonstrate the possibilities of crisis mapping in hands-on tutorials in workshops. The workshops aimed at triggering critical thinking about the current situation compared to the platform capabilities and receive feedback from the actors on the platform design. The data gathered from the interviews and the workshops was then analyzed to update and revise the integrated DERMIS principles.

The data collected from the various interactions and observations, such as interviews, field visits and workshops has been recorded in a case-study based field research approach. The collected recordings and notes have been transcribed and subsequently tagged using the adapted -integrated- DERMIS premises, serving as example design and implementation elements of information systems that contribute to a more integrated information system between communities and formal responding organizations.

[1] https://www.comrades-project.eu
[2] https://ushahidi.io

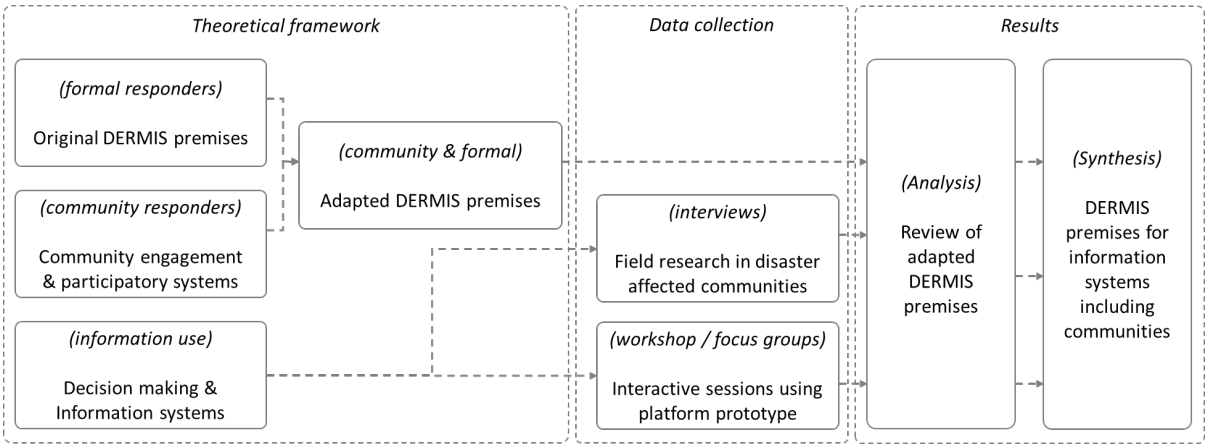


Figure 1: Research methodology

DESIGNING INTEGRATED DERMIS PREMISES

Building on the existing DERMIS premises, we examine how information systems emerge, are designed and used during emergency response in which the affected communities play in active role in the disaster preparedness and response. For this we design the DERMIS premises to be integrated with the existing literature on decentralized coordination, decision making and the use of information systems in such contexts.

Decentralized coordination and decision-making

In the following, we highlight three characteristics of the decentralized coordination and decision-making in disaster relief 2.0 that need to be considered in designing principles for information management: (i) the lack of formal decision support; (ii) the fragmentation and poly-centricity; and (iii) the need to embrace emergence and to design for the context.

(i) Particularly at community level, the decision-making processes for decisions established via analytical models or optimization are often too rigid, too consumptive in terms of resources and cognitive capacity, or simply ineffective. As a result, operational decision-makers typically find themselves engaged in intuitive forms of decision-making (Comes 2016b). Such naturalistic decision-making (Lipshitz et al. 2001) and the connection between sensemaking and decision-making (Gralla et al. 2016; Muhren et al. 2008) or sensemaking and coordination (Van de Walle et al. 2016) have not been translated yet into formalized guiding principles that help design decision support or information sharing taking into account the conditions and requirements of the field.

(ii) A key feature of crisis situations is the multiple agents and units who will perceive themselves, rightly or wrongly, to be in a leadership position or a vital element in the formal chain of command. Dave (2012) in his assessment of ICT for disaster risk reduction in India highlights for example the complex web of government institutions that are involved in handling disasters. Similar phenomena have been observed for different instances of crisis response in Europe (Noori et al. 2016). More recently, Wolbers et al. (2018) introduce the idea of fragmentation in crisis response, highlighting the need for decentralized and local decision-making even for professional responders.

(iii) Frustration with tools owing to lack of coverage and access, complicated interfaces or language barriers will lead communities of reporters, but also professional responders and volunteer & technical communities to revert back to the simplest possible means of communication, particularly in the immediate response (Altay et al. 2014; Comes et al. 2015; Landgren et al. 2007; van den Homberg et al. 2014). The design of information systems must take into account how workflows and processes emerge in the field rather than striving to change patterns that are deeply rooted in cultural and behavioral structures.

DERMIS premises & adaption to decentralized coordination

In the paper by Turoff et al. (2004), based on the various requirements and design approaches, the authors present 9 premises that have been found to be key considerations in the design of information systems used in management of a crisis response. For each of these 9 premises we consider how they can be adapted to reflect the three characteristics of decentralized coordination and decision making listed above.

Premise 1 - System Training and Simulation: "A system that is not used on a regular basis before an emergency will never be of use in an actual emergency."

The operational circumstances of an emergency will allow little room for users to acquaint themselves with a new system. Therefore, authors state that if a system is not used frequently, it will likely not be used during an emergency as users may not be or no longer are familiar with the system. The adoption of systems by communities is driven from different motives then those of formal responders. Where formal responders can be trained in certain systems and processes, or exercise with them during exercises, communities need to rely on different approaches for the adoption of systems (Craig et al. 2002). As communities and community members will not have access to or infrequently use bespoke systems for crisis management, systems that are part of the 'daily life' in communities will be used.

> *Adapted Premise 1:* "Community information systems during crisis response build on systems used in daily (normal) life."

Premise 2 - Information Focus: "Data and information needs to relate to the users dealing with the disaster."

Information systems need to include operationally relevant information. This information needs to be easily accessed, retrieved and represented in a useful format. This includes interactive approaches and dynamic maps, in which users can customize the information they see. Information streams generated to support professional response are currently dominated by advocacy and programming decisions (Comes 2016a). However, information should be relevant to the end-users, as this generates an incentive for user to keep contributing information. It is important to consider activities in communities and examine how these could be strengthen or improved through information. In other words, information in the platform has to be relevant and tailored to a specific user, for example agriculture information may only be relevant to farmers, whereas weather information (alerts) is relevant to the wider community (Paulus et al.).

> *Adapted Premise 2:* "The resilience platform needs to subscribe to the principles of reciprocity and make relevant information available to users at community-level"

Premise 3 - Crisis Memory: "Learning and understanding what actually happened before, during, and after the crisis is extremely important for the improvement of the response process."

A culture of continuous learning should be implemented. This includes a culture of collective mindfulness, and the willingness to learn from past failures (Weick et al. 1999). There are too few reflections and lessons learned due to the reactive nature of crisis interventions and lack of professionalization and training at local level, as well as the lack of an easy to use platform that tracks and monitors events and actions as they unfold over time. Moreover, communities have significant and relevant knowledge about their community, including risks and opportunities related to their resilience (Mayunga 2007). Systems could enable communities to make this knowledge explicit and accessible to both the community and external stakeholders. Communities can also serve as the institutional memory due to their continued presence, the past experiences, and local knowledge.

> *Adapted Premise 3:* "Support the communities in knowledge capture and create an institutional memory which can be shared with other stakeholders."

Premise 4 - Exceptions as Norms: "Almost everything in a crisis is an exception to the norm."

Systems need to be able to adapt to the respective context, in terms of language(s) or pictograms; coverage and network; key issues and needs in the crisis; expertise, skills, and time available of the user. Crisis response information systems rely on standardized products and tools, resulting in the (relatively) rapid and predictable production of e.g. maps, reports, contact lists. Information tailored to the specific context of a disaster, however, is typically not produced, and only available by direct requests. Information systems need to become flexible and agile to adapt to the respective context, in terms of language(s) or pictograms; coverage and network; key issues and needs in the crisis; expertise, skills, and time available of the user (Streefkerk et al. 2014). Furthermore, the systems should also be able to scale up and down, in crisis situations. This is for example an increased flow of information and data, but also multiple (different) users, such as international agencies who can 'plug into' the platform and integrate their systems, making the platform a bridge between the community and other stakeholders (Muhren et al. 2008).

> *Adapted Premise 4:* "Any system developed needs to be able to adapt and be a good fit and tailored to the local context with relevant connections with other systems."

Premise 5 - Scope and Nature of Crisis: "People, authority, and resources need to be brought together at a specific period of time for a specific purpose."

Platforms should support joint data collection and sharing. Despite discussions on interoperability and joint efforts, NGOs and agencies alike are still being asked to fill in different data collection forms across communities. Multiple assessments take place in some areas and no assessments in others; data is collected in different formats by different agencies; and information is not being shared effectively. Information and communication technologies enable contributions from remotely working experts and volunteers. However, with the increasing intervention of people not familiar with the context, control and "ownership" of a crisis may shift towards remote levels. At the same time, communities can contribute important information but require other information to support their decision-making process and maintain their own ownership (Tran et al. 2009).

> *Adapted Premise 5:* "While working on and contributing to a shared set of information, a system can serve different stakeholders each with their own information needs."

Premise 6 - Role Transferability: "It is impossible to predict who will undertake what role. The actions and privileges of the role need to be defined in the software, and people must be trained for the possibility of assuming multiple or changing roles."

Processes and procedures need to be established that give authority to collect and process information to specific roles. Particularly tacit privileges, norms and codes of conduct need to be made transparent through better training and good governance, bringing together tools and practices. At the same time communities undergo changes, so a system should be transferable and aligned with community structures, rather than individual persons. Moreover, the platform should also be able to adopt incoming stakeholders and provide them with the correct role and acces to a system, as well as the information management practices in the community (Smith et al. 2000).

> *Adapted Premise 6:* "Communities undergo changes, so the platform should be transferable and to ensure sustained adoption the platform should fit into community structures and processes."

Premise 7 - Information Validity and Timeliness: "Establishing and supporting confidence in a decision by supplying the best possible up-to-date information is critical to those whose actions may risk lives & resources."

Information cycles need to become predictable and transparent, such that decision-makers can deliberate if the information is sufficiently reliable to decide, or if it is worthwhile to wait for more. This requires that data about the time of the information collection, and its inherent uncertainty, as well as potential implications in terms of humanitarian needs is clearly represented and communicated. Standardized products are available in a relatively short time, though sometimes at the cost of not fulfilling specific information requests. For more specific information needs, it typically takes a longer time to collect, compare and process information. A system should support not only single updates but support a continuous information management process to support forecasting (Kapucu 2008; Thompson et al. 2006).

> *Adapted Premise 7:* "Enabling users to continuously exchange information will add a temporal factor to the information, allowing users to identify trends and developments over time"

Premise 8 - Free Exchange of Information: "Crises involve the necessity for hundreds of individuals from different organizations to freely exchange information, delegate authority, and conduct oversight, without the side effect of information overload."

Shifting formats and the use of different languages hamper access to information, particularly for local actors and emerging actors that do not comply to international humanitarian norms and rules (Harmer et al. 2005). In conflicts, information is often not shared, not even with partners or within the same organization. Standardization and inter-operability of tools and platforms need to be improved, enabling easy access, and offline-modes of work. Common Operational Datasets (CODs) and other information need to be made commonly available and updated at community level. Clear protocols and procedure for sharing information need to be established.

> *Adapted Premise 8:* "Standardization and inter-operability of procedures, tools and platforms are critical, enabling easy access, and offline-modes of work."

Premise 9 – Coordination: "The crux of the coordination is that the exact actions and responsibilities of the individuals cannot be pre-determined."

Research has shown that decisions for disaster coordination are mainly facilitated through organizational structures, collaborative decision processes, and the contribution of advanced information and decision-support systems, all of which are highly interdependent (Chen et al. 2008). While exact actions cannot be predetermined, coordination relies on feedback on the prevalent situation. Response plans are therefore subject to constant change and updates as new information becomes available. Policies that will be developed here will therefore take into

account this flexibility, in order to avoid "threat rigidity", i.e., people following pre-defined, rigid responses while not taking into account the reality of new threats in the crisis situation (Staw et al. 1981). Communities are actively working on their own resilience and have developed structures to support themselves and each other in disaster situations. Rather than supporting a complete or fixed resilience building process, the platform should provide various bits and pieces that communities can use, integrate and apply as they see fit.

> *Adapted Premise 9:* "Any system should not be directive in nature, but rather be flexible to adopt to the structures and process of a community and support self-developed process and goals of the community."

CASE STUDY

To validate the above-mentioned adapted DERMIS premises, with the inclusion of community participation, a case study has been conducted as part of a larger research project related to development of community driven information systems and approaches. The case study is centered around Jakarta, Indonesia, home of 10 million people and it is considered as the fastest sinking city in the world (Chaussard et al. 2013). It has the Java Sea and about 13 rivers running through the city, this continuous influx of water, compounded by the rapid and dense urbanization of the city the capacity of the city makes the city prone to flooding (Abidin et al. 2011).

The study was conducted in November 2018, shortly following the Sulawesi Earthquake and Tsunami and amidst the ongoing efforts of local, national and international agencies to provide assistance to the affected communities in Palu. While our research did not focus on the Sulawesi disaster, the presence of many international agencies and coordinating bodies provided unique opportunities to evaluate the use of information systems in real-time and reflect on the use of information and information systems in these events with the interviewees.

Interviews & Observations

Overall a total of eleven interviews were conducted within two communities in different regions of Jakarta. One situated in Marunda, a frequently affected coastal area which faces both tidal and riverine flooding. And the second in Kampung Melayu, affected by frequent riverine flooding. The interviewees included community leaders of both areas, various community members from diverse backgrounds, including teachers, (factory) workers, youth, families, and elderly people. The interviews took place in the neighborhoods themselves, using a semi-structured approach following the above introduced interview protocol centered around the topics of decisions and decision making, the related information required for these decisions (sources, availability, reliability etc), and the information management approaches and technologies used to facilitate this information exchange.

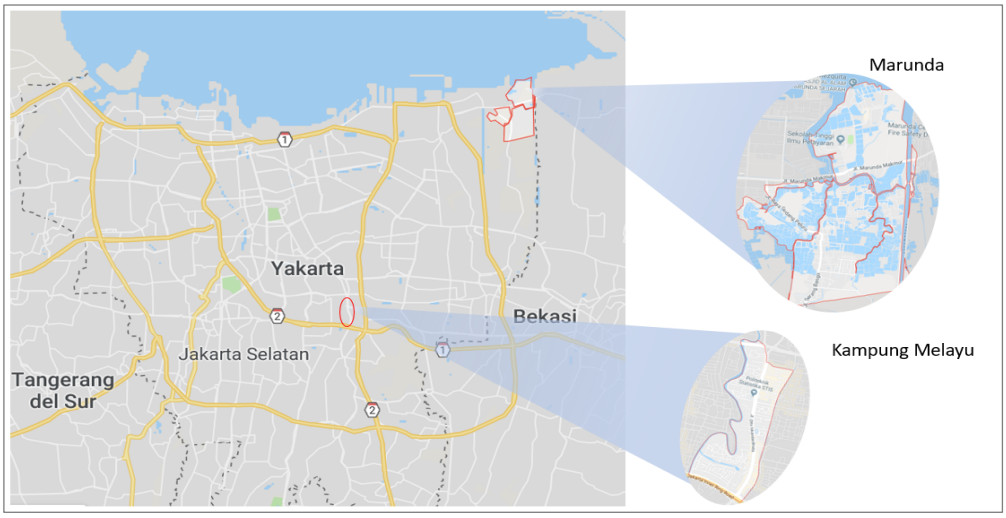


Figure 2: Location of the case studies

Focus Groups & Workshops

In addition to the interviews, the case study also involved focus group sessions with members from (previously) affected communities and formal responders. One focus group was held with five members of a community group actively mapping hazards and risks in their area using the Ushahidi-based COMRADES platform. The second focus group involved a 'Community Coordination Team' responsible for enhancing community disaster preparedness and response.

Furthermore, three workshops were held with members from the V&TCs and affected community to assess and reflect on the usability of an information system designed to exchange information with communities. One workshop was with members of Humanitarian OpenStreet Map, an experienced actor in the field of open mapping for enhancing humanitarian action and community development. A second one was with organized at Pulse Lab Jakarta, a joint initiative of international and national governmental agencies with expertise in the field of big-data and real-time analytics. The final workshop was organized with students from the University of Indonesia. While the first workshops provide insight from experts, which are generally equipped with the required knowledge and skills for information systems design, the latter provided the perspective from local community members.

RESULTS

Using the results from the interviews, workshops and focus groups we review the adapted DERMIS premises. In the following section we review each of the premises and examine if they can be identified in information management approaches and information systems used by communities in the response to crisis situations. Additionally, we look for examples in information systems that are used to exchange information with communities to further if and how these design principles can be manifested in specific examples.

Adapted Premise 1 - Integration into 'daily'' information systems.

The approach of gathering relevant information, according to different community members, is highly personal. Young adults may use social media networks like Twitter or Facebook to search for information while elders rely on their personal knowledge or obtain information from traditional media such as TV. Nevertheless, communication between community members is performed through WhatsApp where they are connected through different groups to family members, community leaders, and in some cases, government officials. The interviews illustrated that in emergency situations, there is usually neither time nor capacity to implement unfamiliar mechanisms. Systems need to be adapted to local the context and capacities and should thus be developed in close collaboration with local partners and integrated in regular and commonly used information systems.

Nov 6, 2018 - Marunda, North-East Jakarta, Indonesia, a community Leader is showing WhatsApp on his mobile phone:

"When flooding occurs, we use mobile phones to inform and be informed by the people in our community. WhatsApp and Facebook are our most important communication tools"

Figure 3: WhatsApp groups used in the community during flooding

Adapted Premise 2 - Reciprocity and offer relevant information

The interviews illustrated that people require specific meaningful information to actively use in decision-making. For instance, the mention of an expected flood holds limited value for a community member, unless the height of the water at the flood gate is mentioned too, as this is used by individuals to assess the likelihood of being affected. At the same time various responders noted that their content is not designed to specifically meet the needs of the affected communities but rather about compliance with standard operating procedures or accountability. With the increased availability of information during crisis situations, one of the challenges is to ensure relevant information is identified and presented to the communities. For this active consideration of the information needs of other information users is needed. While these needs differ between communities and crisis, the ability for a system to support addressing specific information needs should be a key design consideration.

Oct 30, 2018 – South Jakarta, Jakarta, Indonesia, Humanitarian OpenStreetMap team Indonesia

"COMRADES and the new services helps us to better understand unstructured information and find relevant information for different users"

Figure 4: Humanitarian OpenStreetMap using the platform for analyzing community provided reports

Adapted Premise 3 - Support the communities in knowledge creating and capture

The interviews illustrate that there is a vast amount of tacit knowledge developed through past crises on which communities rely to identify and assess the potential impact of crisis or hazard. Information systems can make this tacit local knowledge available to other key stakeholders to identify important of information about the local context. Vice versa, systems can support the community members in effective use of their local knowledge when the right information is delivered. An example thereof, mentioned by community members, is the lack of information regarding possible secondary effects. During recent floods for example, additional rises in the water level occurring after the first flood event were not known to the community, although this did happen in the past. If information about the water levels was continuously provided, community members would possibly make different choices such as evacuation as they had done in previous longer lasting flooding events.

Nov 4, 2018 – South Jakarta, Jakarta, Indonesia, Community Member illustrating floods

"We know what water levels are normally expected when a flood is announced, and we have taken measures to deal with these. However, we don't always have the information to determine if this is going to be worse or not"

Figure 5: Community member illustrating the height of previous floods

Adapted Premise 4 – Tailoring to local context

The communities in our case study are regularly affected by small floods, and therefore not every flood may be cause for alarm or a larger scale response. This example illustrates the need for an information system to be tailored to a local context. Building on the other points of ensuring that information systems are relevant and integrated into community structures, information systems should be able to deal with a range of expectations: the next disaster can fit the regularity of past ones, but it can also be a lot more destructive. In other words, the systems need to be designed in a way that they address frequent emerging information needs in the local community. This enables people to become familiar with information systems and sharing approaches throughout the community.

Nov 4, 2018 – South Jakarta, Jakarta, Indonesia, Community Leader

"It is difficult for me to manage the community response because everyone was doing their own thing without sharing information, eventually leading to a lack of information for decision making."

Figure 6: Community leader along with several community members

Adapted Premise 5 – Tailored presentation and analytics for different stakeholders

Interviewees indicated that allocation of people, authority and resources in case of disasters are a combination of predefined protocols and roles, but also on-the-fly adaptation. In each disaster and community, different people may fulfill a certain role, for example community leaders may share information with community members and/or mediate within other communities and government agencies. Formal responders indicated it would be valuable to identify specific roles of community members in a response, for instance to collect and share information on community needs as this allows the design of information systems to support these roles. However, flexibility in this approach is required since relations and roles differ greatly between communities and disasters. Therefore, a tailored information provision approach, designed for a specific role or decision-making process, is needed.

Nov 4, 2018 – South Jakarta, Jakarta, Indonesia, Community Leader

"We have risk and flood maps provided to us by government agencies, but not everyone has access to the map, knows how to read them or understands what is means for them."

Figure 7: Risk map of community on display in community hall

Adapted Premise 6 - Fit into community structures and processes

The interviews portrayed strong community structures that play a crucial role during emergencies, for example community leaders play an important role in the coordination and exchange of information. In one community a youth group was tasked to use Ushahidi to collect data on risks and hazard in the community. This newly formed group was formed by the community and support by the information system to execute their task. To ensure sustained adoption the system should fit into and support the community structures. The technical complexity of an information system however, requires certain capacities not present in the community themselves, but could be provided by technical volunteers, NGOs or government agencies.

Nov 6, 2018 – North Jakarta, Jakarta, Indonesia, Youth Risk Mapping Group:

"We are using (mobile) technology to continuously asses the risks in our community and use that information to update our disaster preparedness plans"

Figure 8: Youth Risk Mapping group during a focus group discussion

Adapted Premise 7 - Enabling users to continuously exchange information

Interviewees indicated the need of people to have real-time information. An interview with an NGO specialized in the mapping of data for increased resilience indicated furthermore that only real-time usage of data prevents misinformation or information overload. Information provided should focus on the information required for decision-making in that situation. A professional responder with vast experience also indicated that beneficiaries should not be kept in the dark when information is unknown. Information systems should support communities in not only once-off sharing of information but rather managing a continuous stream of information to and from other stakeholders, including other communities' members, NGOs and government agencies.

Nov 7, 2018 –Jakarta, Jakarta, Indonesia, University of Indonesia. A student assuming the role of community leader during a simulation:

"During the simulation it was difficult to maintain an overview as messages from our community members keep coming in via WhatsApp, the situation was constantly changing"

Figure 9: Students building a situational overview during a simulation

Adapted Premise 8 - Standardization and inter-operability of tools and platforms are critical

Communities have information that is relevant to various other stakeholders, such as experiences from previous crisis events, information about the local context and knowledge on their capacities and vulnerabilities. This local knowledge, while valuable, can be disconnected from the formal response. As communities are increasingly also active in the gathering of data as multiple interviewees indicated. A system should assist communities in the connecting their own information management approaches to formal responses. Vice versa, information available to formal responders and their agencies should be shared back to communities.

Nov 9th, 2018 –Central Jakarta, Jakarta, Indonesia. After a demonstration of connecting to the Facebook Messenger and the Humanitarian Data Exchange:

"By connecting to Facebook and the Humanitarian Data Exchange, COMRADES show how to bridge gaps across communities and international organizations"

Figure 10: Demo sharing data via Facebook Messenger with the Humanitarian Data Exchange

Adapted Premise 9 - A system should not be directive in nature

Communities are actively working on their own resilience and have developed structures to respond to disaster situations, often with already set actions and responsibilities and communication channels. However, specific approaches are dependent on the disaster and cannot be fully predetermined. Agency of decision-making lies with community members and complexity increases when information is not available. A system can assist in coordination of non-predetermined actions and responsibilities by informing users on who is doing what and provide checks for accountability. In both the response and preparedness, the information provided serves as trigger and support the decision-making process. I.e. the information provided does not prescribe a certain action but rather supports the user in making informed decisions.

Nov 4, 2018 – South Jakarta, Jakarta, Indonesia, Sunday school Teacher

"Based on the information and support we have received on the risks (flood maps) in our community we have designed our own evacuation routes that we maintain ourselves"

Figure 11: Community designed & maintained evacuation routes

DISCUSSION

The results show that the various DERMIS premises and considerations are relevant and important to the design of information systems in which communities are an active stakeholder and user. Nevertheless, with the existing DERMIS premises mainly focused on the design of information systems for formal responders, the involvement of communities requires a revision of these design principles. While the results above are based on a limited case study through anecdotal evidence, the adapted premises are recognized among both communities and formal responding agencies. Moreover, the results highlight the importance of reconsidering the design principles when involving communities directly in the gathering, analysis and exchange of information. Even though these collected data needs to be closer examined, and the findings further validated, these initial results indicate important considerations for the design of information systems that recognize the role of communities in the information management process.

DERMIS premises applied to community-included information systems

The inclusion of communities as a key stakeholder requires the re-examination of the design principles. The results show that the while the initial ideas of the DERMIS principles still hold true, there are additional implications to be considered. Aside from the above listed results for each of these premises, we found that throughout the interviews, workshops and focus groups several discussions were recurring.

In the design of information systems for community involvement trade-offs have to be made. In contrast with formal responding agencies, communities have other concerns, priorities and core activities (Mayunga 2007; Paton et al. 2001). As such the design, use and maintenance of information systems designed for emergency response management has to be contrasted with these other activities. This requires a balancing trade-off in investments (time, financial, resources) with the prospected benefits of such as system (Liu et al. 2004).

Adoption & Reciprocity

These considerations are closely linked to the adoption of a system. Throughout the interviews and other interactions various other design elements that have proven to be crucial for ensuring an effective information exchange between communities and formal responders have been identified. Finding partners and the embedding of an information system in the community is a key aspect to ensure that these systems are adopted by communities. This applies to communities even more than formal responders, as there is no often mandated need, formal procedure, or 'pressure' to force communities to adopt and use a certain system or information sharing approach (Kapucu 2008; Neef et al. 2014). Nevertheless, there are several measures that can be taken to lower the adopting barrier. First and foremost, building on existing systems, familiar concepts, and in line with existing capacities reduces the need for training and capacity building (Butler et al. 2002).

The recurring and key elements throughout all our interviews however is the engagement and reciprocity of a system. Ensuring that a system provides an added value for the community, ideally on a regular basis and in frequent recurring activities in contrast to systems designed to be used solely during exceptional events. Furthermore, to establish this reciprocity, information systems should cater to the different information needs of users and stakeholders (Janssen et al. 2010).

Emergent nature & adaptive design

Designing information systems for crisis response and disaster management with the inclusion of communities is challenging. First, communities across the globe have different characteristics, not only in terms of the hazards faced or their resilience to withstand them, but also in their capacities and capabilities to provide, use and maintain information and information systems. In short, different disasters affect different communities differently, and due to the volatile and unpredictable nature of disasters the exact requirements of these systems cannot be pre-determined (Kapucu 2008; Maguire et al. 2007). Secondly, at the same time technologies and their use in communities also rapidly change. All these factors combined make it difficult to plan and design information systems for the inclusion of communities ahead of time. Rather it requires deployers of information systems to tailor to the specific requirements of one or more communities before but even during an emergency response.

Although including communities in the design of information systems requires a significant amount of flexibility, adaptability, and resources of information systems and their users, the return of these investments are not only the improved information flows which in turn support the decision-making process. They also support the creation of a more comprehensive and inclusive information system in which different stakeholders -not in the least the communities themselves- have access to and the ability to update relevant information (Craig et al. 2002). Finally, we note that an information system should *trigger* community engagement on response, recovery and long-term

preparedness, but not necessarily organize these efforts in the long term as this often done by communities themselves using their own knowledge, structures, capacities and capabilities. In other words, a system should not be directive or prescriptive but rather provide input, feedback and support into community-based decision-making processes (Almedom 2008; Mayunga 2007).

CONCLUSION

The critical role of communities in disaster response and emergency management is increasingly recognized by various agencies and initiatives. Even when affected themselves, communities have the potential make a valuable contribution to effective disaster response for example by providing access, resources or local knowledge. Today, communities, more than ever before, have options to actively engage and exchange information with responding agencies and the wider public (Crowley et al. 2010).

As information and communication technologies become increasingly more common throughout the world, more and more people gain access to new opportunities to collect, analyze and share information. These developments are supporting the increased democratization of information, not in the least during emergency responses. An increasing number of platforms, initiatives and projects emerge that support and encourage new and old players to participate in information management processes in the response to a disaster.

These increased trends of active participation in the decision making and information processes of communities, require a re-examination of the design and approach used in information management systems. When properly designed information systems not only facilitate the information exchange between different groups such as communities, formal agencies and volunteer organizations, but contribute to a more efficient and effective response by actively addressing information gaps, transforming data into actionable information and presenting relevant information to empower different users in their decision-making processes (Comes et al. 2017; Kapucu 2008).

Limitations & Future research

The work presented in this paper reveals the initial results of the ongoing work for community inclusive information systems design for crisis response and management. Building on the DERMIS premises for the design of information systems for emergency response, we have re-examined these design principles in light of the developments of increased participation of communities in information management processes and activities.

The results presented in this paper are based on a single case study conducted in Indonesia in the wake of 2018 Sulawesi Tsunami. Future work would not only focus on strengthening these results by verifying these findings in multiple studies including different contexts, but also extend beyond the current DERMIS principles. The scope of the planned future work includes the identification of possible additional principles, some of which -such as reciprocity- are highlighted already in the discussion. Future study would there focus on a more grounded approach towards identifying critical design elements and success factors for inclusive information systems. Additionally these studies would also examine the trade-offs between various design principles as well as the fit with local circumstances, capacities and resources in particular in the aftermath of a disruptive event.

While this single case-study and the preliminary results do not provide a comprehensive review of the DERMIS design principles in light of community inclusion, the results do indicate important findings that warrant further examination. Especially in light of the ongoing democratization of information and information systems, with more and more communities gaining access to and the ability to share information during disaster responses.

Acknowledgements

We thank the various groups and interviewees for their time and insights. In particular we thank Humanitarian OpenStreetMap Team (HOT) Indonesia, KARINA Yogyakarta, and the communities in Jakarta for their support.

REFERENCES

Abidin, H. Z., Andreas, H., Gumilar, I., Fukuda, Y., Pohan, Y. E., and Deguchi, T. 2011. "Land subsidence of Jakarta (Indonesia) and its relation with urban development," *Natural Hazards* (59:3), p 1753.

Almedom, A. M. 2008. "Resilience to disasters: a paradigm shift from vulnerability to strength," *African Health Sciences* (8:Suppl 1), p S1.

Altay, N., and Labonte, M. 2014. "Challenges in humanitarian information management and exchange: evidence from Haiti," *Disasters* (38 Suppl 1), pp S50-72.

Baharmand, H., Boersma, K., Meesters, K., Mulder, F., and Wolbers, J. Year. "A multidisciplinary perspective on supporting community disaster resilience in Nepal," ISCRAM2016.

Basu, M., Ghosh, S., Jana, A., Bandyopadhyay, S., and Singh, R. 2017. "Resource mapping during a natural disaster: a case study on the 2015 Nepal earthquake," *International journal of disaster risk reduction* (24), pp 24-31.

Butler, D. L., and Sellbom, M. 2002. "Barriers to adopting technology," *Educause Quarterly* (2:1), pp 22-28.

Chaussard, E., Amelung, F., Abidin, H., and Hong, S.-H. 2013. "Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction," *Remote Sensing of Environment* (128), pp 150-161.

Chen, R., Sharman, R., Rao, H. R., and Upadhyaya, S. J. 2008. "Coordination in emergency response management," *Communications of the ACM* (51:5), pp 66-73.

Comes, T. Year. "Cognitive biases in humanitarian sensemaking and decision-making lessons from field research," Cognitive Methods in Situation Awareness and Decision Support (CogSIMA), 2016 IEEE International Multi-Disciplinary Conference on, IEEE2016a, pp. 56-62.

Comes, T. Year. "Cognitive biases in humanitarian sensemaking and decision-making lessons from field research," IEEE2016b, pp. 56-62.

Comes, T. 2016c. "Designing for networked community resilience," *Procedia engineering* (159), pp 6-11.

Comes, T., Meesters, K., and Torjesen, S. 2017. "Making sense of crises: the implications of information asymmetries for resilience and social justice in disaster-ridden communities," *Sustainable and Resilient Infrastructure*), pp 1-13.

Comes, T., Vybornova, O., and Van de Walle, B. Year. "Bringing Structure to the Disaster Data Typhoon : An Analysis of Decision-Makers ' Information Needs in the Response to Haiyan," AAAI Spring Symposium, Stanford, 2015, pp. 7-11.

Comfort, L. K., Ko, K., and Zagorecki, A. 2004. "Coordination in rapidly evolving disaster response systems: the role of information," *American Behavioral Scientist* (48:3), pp 295-313.

Craig, W. J., Harris, T. M., and Weiner, D. 2002. "Community participation and geographic information systems," in *Community Participation and Geographical Information Systems*, CRC Press, pp. 29-42.

Crowley, J., and Chan, J. 2010. "Disaster Relief 2.0: The future of information sharing in humanitarian emergencies," HHI, Washington D.C.

Dave, R. 2012. "Developing ICT infrastructure for Disaster Risk Reduction (DRR) in India,").

Debnath, P., Haque, S., Bandyopadhyay, S., and Roy, S. Year. "Post-disaster Situational Analysis from WhatsApp Group Chats of Emergency Response Providers," ISCRAM2016.

Gralla, E., Goentzel, J., and Fine, C. 2016. "Problem Formulation and Solution Mechanisms : A Behavioral Study of Humanitarian Transportation Planning," *POMS* (25:1), pp 22-35.

Gralla, E., Goentzel, J., and Van de Walle, B. 2013. "Field-Based Decision Makers' Information Needs," *Digital Humanitarian Network, Geneva*).

Harbers, M., Aydogan, R., Jonker, C. M., and Neerincx, M. A. Year. "Sharing information in teams: giving up privacy or compromising on team performance?," Proceedings of the 2014 international conference on Autonomous agents and multi-agent systems, International Foundation for Autonomous Agents and Multiagent Systems2014, pp. 413-420.

Harmer, A., Cotterrell, L., and Institute, L. O. D. 2005. *Diversity in donorship: The changing landscape of official humanitarian aid*, (Humanitarian Policy Group, Overseas Development Institute.

IFRC 2005. "Data or dialogue? The role of information in disasters," International Federation of Red Cross and Red Crescent Societies, Geneva.

Janssen, M., Lee, J., Bharosa, N., and Cresswell, A. 2010. "Advances in multi-agency disaster management: Key elements in disaster research," *Information Systems Frontiers* (12:1), pp 1-7.

Kapucu, N. 2008. "Collaborative emergency management: better community organising, better public preparedness and response," *Disasters* (32:2), pp 239-262.

Landgren, J., and Nulden, U. Year. "A study of emergency response work: patterns of mobile phone interaction," CHI, ACM, New York, 2007, pp. 1323-1332.

Lipshitz, R., Klein, G., Orasanu, J., and Salas, E. 2001. "Taking stock of naturalistic decision making," *Journal of Behavioral Decision Making* (14:5), pp 331-352.

Liu, L., and Yu, E. 2004. "Designing information systems in social context: a goal and scenario modelling

approach," *Information systems* (29:2), pp 187-203.
Maguire, B., and Hagan, P. 2007. "Disasters and communities: understanding social resilience," *Australian Journal of Emergency Management, The* (22:2), p 16.
Mayunga, J. S. 2007. "Understanding and applying the concept of community disaster resilience: a capital-based approach," *Summer academy for social vulnerability and resilience building* (1), p 16.
Meesters, K. Year. "Towards using Serious Games for realistic evaluation of disaster management IT tools," AIM SG2014, pp. 38-48.
Meier, P. Year. "Next generation humanitarian computing," Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing, ACM2014, pp. 1573-1573.
Muhren, W., Eede, G. V. D., and Van de Walle, B. 2008. "Sensemaking and implications for information systems design: Findings from the Democratic Republic of Congo's ongoing crisis," *Information technology for development* (14:3), pp 197-212.
Munro, R. 2012. "Crowdsourcing and the crisis-affected community," *Information Retrieval*), pp 1-57.
Neef, M., van Dongen, K., and Rijken, M. Year. "The COBACORE Project–a Community-Based Approach to Disaster Recovery," Proceedings of the 9th Future Security Research Conference2014.
Nespeca, V., Meesters, K., and Comes, T. "Evaluating Platforms for Community Sensemaking: Using the Case of the Kenyan Elections,").
Noori, N. S., Wolbers, J., Boersma, K., and Vilasís-Cardona, X. Year. "A Dynamic Perspective of Emerging Coordination Clusters in Crisis Response Networks," 2016.
Okolloh, O. 2009. "Ushahidi, or 'testimony': Web 2.0 tools for crowdsourcing crisis information," *Participatory learning and action* (59:1), pp 65-70.
Paton, D., and Johnston, D. 2001. "Disasters and communities: vulnerability, resilience and preparedness," *Disaster Prevention and Management: An International Journal* (10:4), pp 270-277.
Paulus, D., Meesters, K., and Van de Walle, B. "Turning data into action: supporting humanitarian field workers with open data,").
Piccolo, L. S., Meesters, K., and Roberts, S. Year. "Building a Socio-technical Perspective of Community Resilience with a Semiotic Approach," International Conference on Informatics and Semiotics in Organisations, Springer2018, pp. 22-32.
Sebastian, A., Lendering, K., Kothuis, B., Brand, A., Jonkman, S., van Gelder, P., Kolen, B., Comes, M., Lhermitte, S., and Meesters, K. 2017. "Hurricane Harvey Report: A fact-finding effort in the direct aftermath of Hurricane Harvey in the Greater Houston Region,").
Smith, W., and Dowell, J. 2000. "A case study of co-ordinative decision-making in disaster management," *Ergonomics* (43:8), pp 1153-1166.
Staw, B. M., Sandelands, L. E., and Dutton, J. E. 1981. "Threat rigidity effects in organizational behavior: A multilevel analysis," *Administrative science quarterly*), pp 501-524.
Streefkerk, J. W., Neef, M., Meesters, K., Pieneman, R., and van Dongen, K. Year. "HCI challenges for community-based disaster recovery," International Conference on Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management, Springer2014, pp. 637-648.
Thompson, S. M., Altay, N., Green III, W. G., and Lapetina, J. 2006. "Improving disaster response efforts with decision support systems," *International Journal of Emergency Management* (3:4), p 250.
Tran, P., Shaw, R., Chantry, G., and Norton, J. 2009. "GIS and local knowledge in disaster management: a case study of flood risk mapping in Viet Nam," *Disasters* (33:1), pp 152-169.
Turoff, M., Chumer, M., de Walle, B. V., and Yao, X. 2004. "The design of a dynamic emergency response management information system (DERMIS)," *Journal of Information Technology Theory and Application (JITTA)* (5:4), p 3.
Twigg, J. 1999. "The age of accountability?: future community involvement in disaster reduction," *Australian Journal of Emergency Management, The* (14:4), p 51.
Van de Walle, B., Brugghemans, B., and Comes, T. 2016. "Improving situation awareness in crisis response teams: An experimental analysis of enriched information and centralized coordination," *International Journal of Human-Computer Studies*).
van den Homberg, M., Meesters, K., and Van de Walle, B. 2014. "Coordination and Information Management in the Haiyan Response: observations from the field," *Procedia Engineering* (78), pp 49-51.
Weick, K. E., and Quinn, R. E. 1999. "Organizational change and development," *Annual review of psychology* (50:1), pp 361-386.
Weiss, T. G. 1999. "Principles, politics, and humanitarian action," *Ethics & International Affairs* (13), pp 1-22.
Wolbers, J., Boersma, K., and Groenewegen, P. 2018. "Introducing a fragmentation perspective on coordination in crisis management," *Organization Studies* (39:11), pp 1521-1546.

The reciprocity of data integration in disaster risk analysis

David Paulus
PhD Researcher
Policy Analysis Section
TU Delft
d.paulus@tudelft.nl

Kenny Meesters
PhD Researcher
Policy Analysis Section
TU Delft
K.J.M.G.Meesters@tudelft.nl

Gerdien de Vries
Assistant Professor
Organisation & Governance Section
TU Delft
G.deVries-2@tudelft.nl

Bartel Van de Walle
Professor
Head of Multi-Actor Systems Department
TU Delft
B.A.vandeWalle@tudelft.nl

ABSTRACT

Humanitarian organizations are increasingly challenged by the amount of data available to drive their decisions. Useful data can come from many sources, exists in different formats, and merging it into a basis for analysis and planning often exceeds organizations' capacities and resources. At the same time, affected communities' participation in decision making processes is often hindered by a lack of information and data literacy capacities within the communities. We describe a participatory disaster risk analysis project in the central Philippines where the community and a humanitarian NGO worked towards a joint understanding of disaster risks and coping capacities through data integration and IT-supported analysis. We present findings from workshops, focus group discussions and semi-structured interviews, showing the reciprocal effects of the collaborative work. While the community valued the systematically gathered and structured evidence that supported their own risk perceptions and advocacy efforts, the humanitarian NGO revisited established work practices for data collection for analysis and planning.

Keywords

Reciprocity, Resilience, Disaster risk analysis, Community engagement, Organizational effectiveness, Data integration

INTRODUCTION

To prepare for the events of natural hazards, stakeholders of climate change adaptation (CCA) and disaster risk reduction (DRR) programs try to understand capacities and vulnerabilities of potentially affected communities (Mercer et al., 2010). This requires gathering and understanding data from various sources (Kawasaki et al., 2017). Useful data can come from many sources, exists in different formats, and merging it into a basis for analysis and planning often exceeds organizations' capacities and resources. Household surveys are frequently conducted by DRR program stakeholders and are a well-established tool to capture field realities. They provide information on demographics, education levels, income types and salary levels (Morin et al., 2016). And they can capture people's perceptions of risks and capacities in their neighborhoods (Sullivan-Wiley & Short Gianotti, 2017).

Official data from government agencies, e.g. censuses, are increasingly published openly in light of open government initiatives (Janssen et al., 2012). Recently, aid organizations increasingly publish and share data on their activities (IATI, 2017; UNOCHA, 2018), which in turn can be useful information for other organizations (Crowley et al., 2011). Examples are data created through the International Aid Transparency Initiative (IATI)[1] and the Humanitarian Data Exchange (HDX)[2]. In combination with organizations' own data creation efforts, this leads to an increasingly difficult task of data integration and sense making.

[1] https://iatistandard.org
[2] https://data.humdata.org

Problem statement

While these initiatives are deployed to increase the data availability, analysis and use in decision making processes, these initiatives are often centered around humanitarian organizations, their objectives and requirements. Notwithstanding the objective of humanitarian organization to alleviate human suffering and strengthening communities by increasing their resilience to disruptive events (Weiss, 1999), often the main focus of data collection and processing is to ensure effective humanitarian operations, informed decision making or provide accountability on an organizational level (Comfort et al. 2004; Gralla et al. 2013). Subsequently, with the rise of technologies and data in the humanitarian field, various platforms, tools and systems have been provided to humanitarian organizations to support their needs assessments, operations and impact evaluations (Crowley et al. 2011).

Consultations of affected communities are the fundament of most CCA and DRR programs. Data are gathered from assessments and then analyzed and interpreted by organizations to plan their program implementation. This often moves communities into passive roles as data providers who are excluded from analysis, interpretation and decision making processes (Streefkerk et al., 2014). This stands in contrast with arguments from the social resilience literature (Comes et al., 2017) that emphasizes the importance of building resilience by increasing community capacities, resources and ownership (Maskrey, 1989).

With the increased importance of data and IT-tools in humanitarian operations, such capacities become critical elements for the empowerment of communities to self-organize preparations and responses to disasters (Baharmand et al., 2016; Kapucu, 2008; Kendra et al., 2007). However, communities - in contrast to humanitarian organizations - often have less access to specific technologies and resources to implement and use supportive systems. Their capabilities to employ data-driven assessments remain limited (Piccolo et al., 2018; Streefkerk et al., 2014).

Research objective

We examine how, through the use of modern technologies, this discrepancy can be resolved. Specifically, through (1) building an understanding of information needs and offers of communities and organizations, (2) streamlining data gathering and analysis, and (3) a redistribution of processes around data that builds on and strengthens local capacities.

In the remainder of this paper we first discuss the current state of research around data-driven humanitarian operations which leads to the uncovering of the above briefly outlined research gap: how can communities and humanitarian organizations jointly build an understanding of risks, vulnerabilities and capacities to support community-driven resilience and mitigation efforts? We then describe our research approach, using a prototypical process implemented in a CCA and DRR program in the Philippines, of how such joint efforts could be shaped in practice. This is followed by the description of results, both solely technical as well as reciprocal, meaning the mutual influences between system, community and organization. We conclude the paper with a discussion of the results and prospects for future research.

PREVIOUS RESEARCH

In previous research Van Den Homberg et al. (2014), Gralla et al. (2015) and Comes et al. (2017) investigated information needs of humanitarian organizations and affected communities. We argue that information needs identified by them, also apply to CCA and DRR program stakeholders in our case study. In the field of humanitarian logistics Link et al. (2015) stressed the importance of data integration during disaster preparedness activities and structured humanitarian logistics information into three categories which determine when certain information is needed: during the rapid response, ongoing response or preparedness phase. Horita et al. (2014) developed the humanitarian logistics infrastructure and resource model to integrate volunteered geographic information into humanitarian logistics processes. The usefulness of the integration of data initiatives like IATI and HDX for humanitarian organizations and affected communities was suggested by Paulus et al. (2018). They outlined an information system design approach to address questions that arise during different phases of humanitarian activity. Muhren et al. (2010) and Van de Walle et al. (2016) stressed the role of information on situational awareness, sense making and decision making and formulated fundamental design principles for data systems that support individuals and groups in these activities. Information systems, according to DeLone and McLean (2003) are comprised of a multitude of factors, and not only describe technical artifacts. They also include the human and organizational factors, that should not only be considered as part of the design and performance of

an information system but are in fact an integral part that determine the effectiveness of such a system to achieve organizational goals. Formalized community engagement principles like the empirically-based EnRiCH community resilience framework for high-risk populations have emphasized empowerment and collaboration as crucial drivers of adaptive capacity (O'Sullivan et al., 2014). While the importance of community engagement in disaster preparedness efforts is acknowledged and success factors have been defined (Mays et al. 2014), surprisingly few studies analyzed the reciprocal effects of disaster information systems and community engagement efforts (Ahmed et al. 2012).

From these previous findings we draw that the reciprocal effects of data-driven and IT-supported methods for community-centered disaster risk reduction projects have not been investigated substantially. In this paper we will therefore assess these effects by employing the development, testing and evaluation of a software prototype for data integration and analysis into a DRR program.

SELECTED CASE

The research was conducted within a CCA and DRR program in Jagobiao, an urban poor community of approximately 14.000 people near Cebu City, Central Philippines. The implementing organization had established close ties to the Jagobiao community, local government authorities, local faith-based groups and the local disaster risk management office over the past years. The community, administratively divided into several districts, held frequent self-organized gatherings during which risks and capacities were collected and potential mitigation and supportive measures were discussed. One outcome of these gatherings were hand-drawn maps per district and per hazard with color-coded households according to the perceived risk level for each household. The maps further contained community capacities, for example evacuation centers, hospitals and water wells. Another community-driven activity was the conducting of household surveys of the community's youth group. The surveys captured per household demographics and characteristics, for example building material, proximity to shoreline and household income. These community-driven activities to capture local knowledge lead to a volume of data that the program stakeholders were unable to process, analyze and interpret effectively.

RESEARCH APPROACH

As per the case description, data integration and analysis became the major concern of the program stakeholders and hindered the development of a common understanding of the community's risks and capacities. The process towards a more streamlined approach to data integration and analysis through the incremental development of a supportive software prototype is described in this section. We start with describing the process through the lens of Action Design Research (ADR) by Sein et al. (2011). Table 1 summarizes the process.

Table 1. The development process from ADR perspective. Adapted from (Sein et al. 2011)

Stages and Principles		Artifact
Stage 1: Problem Formulation		
Principle 1: Practice-Inspired Research	Research project was initiated to identify concrete information challenges and possible information system solutions in the selected DRR project.	***Recognition***: Existing work practices, used tools and available data did not satisfy organizational objectives to understand risks, vulnerabilities and capacities of the local community.
Principle 2: Theory-Ingrained Artifact	Participatory disaster risk assessment.	
Stage 2: Building, Intervention, Evaluation		
Principle 3: Reciprocal Shaping	Indicator definitions and survey data was either lacking or not systematically created. Continuously during the research project, the stakeholders collaborated to design processes and requirements to address both issues.	***Alpha Version****:* The prototype should streamline the data integration and analysis process.
Principle 4: Mutually Influential Roles	The group of stakeholders consisted of researchers, NGO staff, local government agency officials as well as representatives of the local community and a local faith-based organization. Thus, scientific, practical and policy perspectives were taken into account.	***Beta Version*:** The analysis offered by the prototype should be based on systematically created indicators and data.
Principle 5: Authentic and Concurrent Evaluation	First evaluations were conducted by the researchers and NGO staff and then with the other stakeholders. Also further international offices of the NGO tested the prototype during development.	
Stage 3: Reflection and Learning		
Principle 6:	The NGO recognized potentials for improving work practices regarding systematic data collection and analysis. The local	***Emerging Version and Realization***: Additional requirements for the

Guided Emergence	government agency reflected on use cases for a broader roll-out of the system within its mandate area. The community valued the novel approach as an additional source of evidence for their own advocacy campaigns. System design requirements for the different stakeholders emerged.	prototype, especially regarding the multi-hazard context of the community. More dynamic and flexible prototype structure needed.
Stage 4: Formalization of Learning		
Principle 7: Generalized Outcomes	Concrete requirements for a first prototypical system version and for a more advanced later version were captured. Regarding the system as an integral future tool for analysis and planning of DRR programs.	***Ensemble Version***: Due to time-constraints, the development remained in the prototype stage.

Requirement analysis

Specific requirements for the prototype were continuously generated and adapted from discussions, workshops, interviews and observations with the DRR program stakeholders during field visits to the case area and remotely. General requirements were drawn from information system design literature and previous studies on information system development for DRR and crisis response (Turoff et al., 2004). According to the technology acceptance model, perceived usefulness and perceived ease-of-use are the major influential factors that determine if new information systems will be used (Davis, 1989; Davis et al., 1989). In the case described here, involved stakeholders IT literacy and experience varied strongly: from advanced experience within the government agency to mid-skilled humanitarian NGO staff to local community people with rather low IT literacy. The development process of the prototype needed to take this capacity diversity into account to facilitate adoption (Maiers et al., 2005). It became evident that a successful approach would need to consider processes and tools already implemented and used by the program stakeholders.

Development and Feedback Process

The prototype was developed with three core components: 1) a dashboard acting as the tool for analysis, 2) the data processing layer and 3) an API layer to retrieve external data and allow integration with other applications. A feedback process was set up that included stakeholders of the CCA and DRR program. Table 2 lists the participants and their involvement in the feedback process. Feedback data collection was conducted through semi-structured interviews, focus group discussions, workshops, field observations as well as e-mail and Skype conversations.

As a foundation for the development of the prototype, a dashboard previously developed by UNOCHA was used. It was open to adaptation, fulfilled sufficient aspects for dashboard design (Janes et al., 2013) and already provided some of the main requirements needed for the prototype. This included the interrelation of charts, a map and processing functions for household survey data on demographics, capacities and vulnerabilities of communities. During the parallel development and evaluation process we added the selection of hazards, the simulation of hazard intensities, substantially more charts on household capacities as well as dynamic map features and more interrelations between the charts and the map.

Within the data processing layer, the prototype does not store any data. Rather, the user needs to be in the possession of the data at all time. This eliminates the possibilities of malicious system infiltration and leakages of sensitive data. JavaScript code is sent by the server to the user and executed on the user's machine. Thus, when using the dashboard, both data and application are running on the user side. The decision on this form of data handling was made due to concerns raised by the community. Some members regarded the data being used by the prototype as too sensitive and personal and expected this additional security feature to prevent malicious actors from accessing it unauthorized. The decision is further supported by recent arguments within the debate on data management in humanitarian operations. Especially in political sensitive contexts, household and demographic data can be highly valuable for the different conflicting parties (Greenwood et al. 2017).

Three datasets are needed to run the prototype:

- Survey data (csv-file): Can be created in Excel or from a KoboToolbox[3] export, or any other survey platform. The internal data structure and terminology of the prototype needs to be followed.
- 3W data (csv-file): Can be created in Excel. It comprises local knowledge from DRR program stakeholders on relevant organizations, groups and networks. To complement the 3W data, information from IATI and HDX are fetched.
- Geographic features (kml-file): Can be created in Google Earth. Includes local knowledge from DRR

[3] https://www.kobotoolbox.org/

program stakeholders on important geographic features in the case area, e.g. evacuation centers, wells and water flows.

The choices for the data creation tools, Microsoft Excel, KoboToolbox and Google Earth, were made during stakeholder discussions and successive testing of the prototype during development. The three tools were well-known by most of the stakeholders. No additional training was needed.

Table 2. Methods of feedback collection and relations to stakeholder affiliations.

Group or organization	Interviewee affiliation (n)	Feedback collected via
International humanitarian NGO	Head of mission (1) Data analyst (1)	Interviews, focus group discussions, e-mails, Skype
Local disaster risk management office	Data analyst (1)	Interviews, focus group discussions
Local faith-based organization	Data analyst (2)	Interviews, focus group discussions
Local community	Priest (1) District representatives (5)	Focus group discussions

RESULTS

We present the results in the following first from a purely technical perspective, followed by the observed reciprocal results of the effects between system prototype development, community and organization.

Technical results

The prototype's visual user interface is a single-page dashboard made up of a map, charts, tabularized information and buttons as control elements. The three main components are depicted in figures 1-3. Figure 1 shows how the prototype visualizes community demographics. The bars and slices in the charts are clickable to allow the selection of a certain kind of data only. For example, clicking on a single district (i.e. a slice) in the Sitio pie chart, manipulates the gender pie chart in a way that it only shows the gender proportion within the selected district. Selecting multiple districts leads to the gender chart showing the combined gender proportions within all selected districts. All other charts are affected at the same time: the age chart shows the age structure and the affiliation chart shows the job title distribution within the selected districts. This works in all ways, e.g. starting from selecting affiliations or age groups instead of starting from districts. Data categories can be combined by selecting various slices from various charts. Users thereby can answer questions like: *how many females above 60 years of age live in Sitio Santa Cruz?*

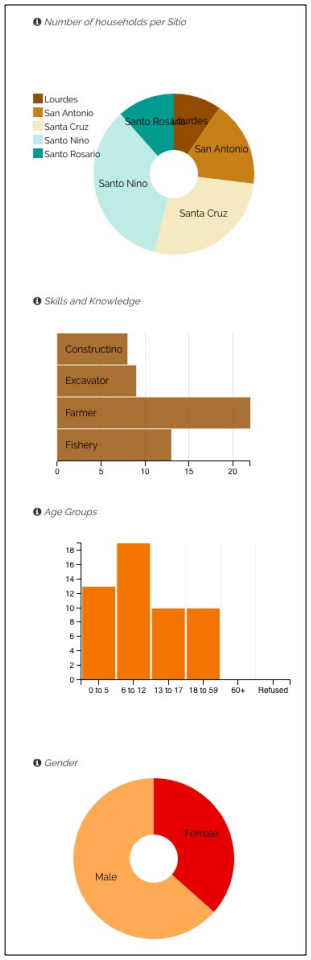


Figure 1. Community demographics charts.

Figure 2 shows the mapping of households at risk of being affected by different hazards within the community. Implemented were the main hazards identified by the stakeholders: flood, fire, typhoon and drought. The colored buttons below the map allow for simulating the intensity of those hazards, which in turn has an effect on the number of households potentially affected and highlighted on the map. Via the map legend, features like evacuation centers, wells and water flows can be added to the map. Clicking on a household dot shows its key information including age structure and income level. Making selections via the demographics charts, for example selecting only those households with small children, renders the map new, only showing households that match the selection criteria.

Figure 3 shows two example charts that visualize capacities and vulnerabilities of households in the community. These had been identified during the workshops and discussions with the stakeholders. Again, these charts are intertwined with the demographics charts and the map. Allowing users to answer questions like: *what districts have the most small children and elderly people living in light material housing in low elevation areas?*

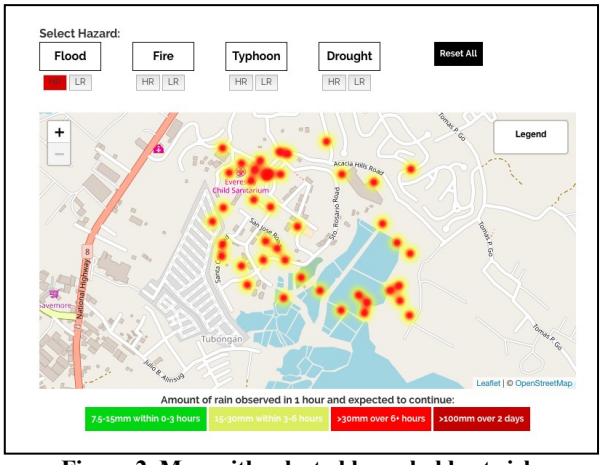


Figure 2. Map with selected households at risk.

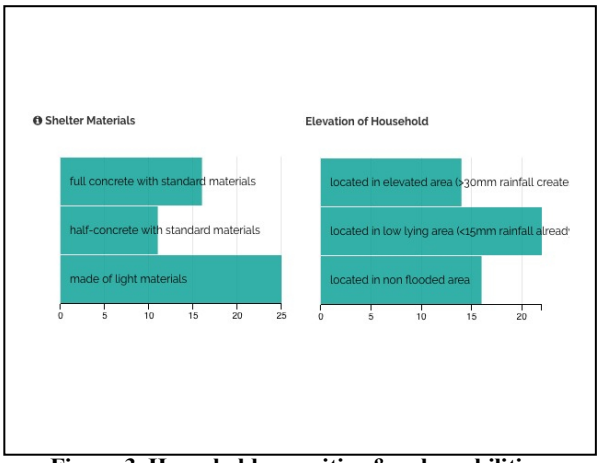


Figure 3. Household capacities & vulnerabilities.

Reciprocal results

Within the NGO, the work on the systematic creation of indicators and the collection of data lead to a reconsideration of established work practices. Figure 4 depicts how the organization tried to assess risk levels prior to the work on the prototype. The amount of data collected and the complexity of relations between capacities, risks and vulnerabilities blurred the organization's view on what the key issues were in the community and what caused them. As shown in figure 4, the previous mapping approach included a number of data layers but their integration was lacking. It didn't allow answering questions like: *how many elderly people and children under five live in light-material buildings in typhoon prone areas?* This was only possible with the new prototype where combining variables for integrated analysis became possible. The community members valued the prototype and the development approach leading to it, as helpful in their objective understanding of the risks they face as well as a validation of their subjective risk perception. They acknowledged the prototype as a supportive vehicle that could facilitate their own community-driven initiatives to raise awareness of their case at the local government level. The local government agency mentioned that a final version of the prototype could be rolled out to the whole province of Cebu, covering an area of approximately 3 million people. The agency stressed the importance of a flexible system open to future adaptations and implemented through technologies already employed by the agency.

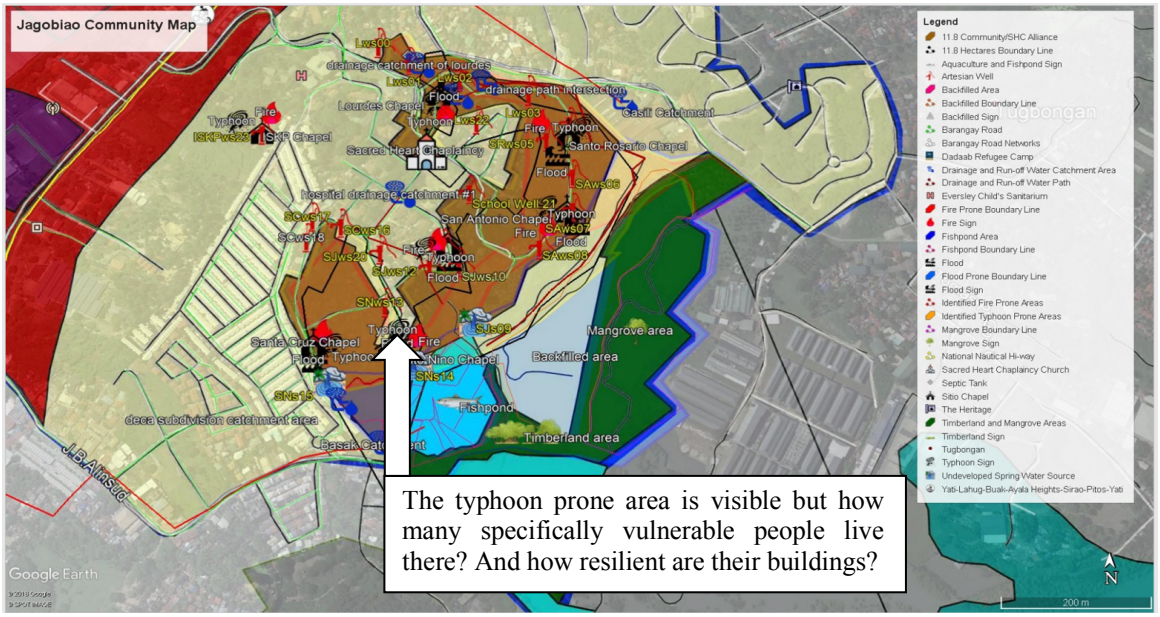


Figure 4. Layered map created and used by the NGO for DRR analysis prior to the prototype development.

DISCUSSION

Throughout the participatory approach towards designing the system prototype, we uncovered critical elements for the continued engagement of the community in the data management processes. Taking these design considerations into account enables communities to not only gather data themselves but also analyze it and support their own, internal, sense making and decision making processes. The inclusion of the community in the design, development and testing of the system does not only improve adoption but also supports the building of key capacities and data literacy skills. The end goal of data preparedness therefore is not merely the creation of data-sets but rather a collaborative learning process in which the community examines their information needs, capacities and tools needed (Norris et al. 2008). Data preparedness activities therefore should not only focus on making communities visible on maps, but build necessary capacities that lead to community-driven, collaborative programs and an active exchange of data and knowledge.

These capacities are critical for community resilience as they enable them to actively participate in the decision-making processes (Nur et al. 2015; Onencan et al. 2018). They can build a stronger evidence-base by continuously generating and sharing information that places these empowered communities firmly in the local, regional, national and even international stakeholder landscape (Kapucu 2008; Mayunga 2007).

All interviewees stressed that it is of major importance to understand and comply with data rights of communities and affected persons. This does not only include data privacy and security. But also, the rights of data subjects to get access to information about them when requested, to have information about them changed when wrong, to be informed about how information about them is stored, processed and used and to what purpose and result.

The joint disaster risk analysis and prototype development have created a paradigm shift in the role of the community in the overall information management process. Where initially the role of the community was primarily the one as data provider, the new design has led to a more collaborative information gathering, analysis and dissemination approach in which local actors play a more empowered role. Figure 5 depicts this shift, with the former data relationships between DRR program stakeholders on the left side and on the right side the new, joint cooperation to build a common understanding of risks and capacities. The dotted lines represent the newly formed communication and collaboration links between the community and the NGO, and all other previously established forms of collaboration and exchange further exist.

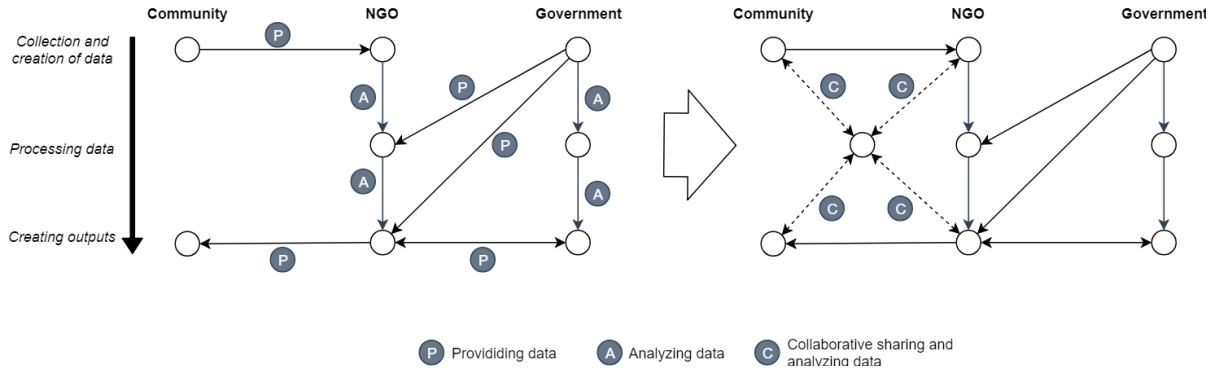


Figure 5. How data relationships changed from the traditional model of data collection, analysis and provision to the novel, joint assessment model.

CONCLUSION

The most striking observation was that the community and the humanitarian organizations recognized significant reciprocal effects between the development of the prototype and their work practices. They revisited established data collection and analysis practices while seeing the prototype advance, testing it and giving feedback on it. The stakeholders acknowledged that the existing data gathering, and creation processes were not systematic enough to lead to robust risk and capacity indicators and variables.

We used prototypical software development and a diverse feedback collection process to study what information needs communities and humanitarian organizations have and how streamlined data integration and analysis can

help in addressing these needs. We found evidence for the usefulness of data integration for various stakeholders of DRR programs: humanitarian organizations, local communities, government agencies and faith-based organizations.

The increased availability of data to support humanitarian operations, spurred on by the profusion of information technologies that facilitate data collection, analysis and sharing, have led to a *data revolution* in the humanitarian field. Increasingly, organizations, donors and policy makers place a strong emphasis on the use of data for effective operations, evidence-based decision making and accountability. At the same time the potential of data in the humanitarian field has also led to an increased attention for communities to become prepared and 'data-ready'. As a result, more and more datasets become available, strengthening the potential of data to ensure effective aid delivery to those in need.

Throughout our participatory approach towards designing a novel disaster risk analysis prototype, we uncovered critical elements for the continued engagement of the community in the data management processes. Taking these design considerations into account enables communities to not only gather data themselves but also analyze it and support their own, internal, sense making and decision making processes. More important than the design of the system itself however, is the inclusion of the community in the design, development and testing of the system as this does not only improve the probability of adoption but also supports the building of key capacities for local disaster risk mitigation, preparedness, response and recovery efforts.

LIMITATIONS AND FUTURE RESEARCH

The work presented in this paper is limited to a single case study, and in our future work we aim to expand our work to other regions and settings to further validate the findings presented in this study. In addition to the further validation of the work, a key aspect is the continued exploration of the participatory design of data management processes and information systems. Specifically, various approaches towards capacity building and training, also raised during interviews and focus group discussions, need to be further investigated. Another interesting further endeavour is to study how decisions from humanitarian organisations are affected by how the evidence that results from the streamlined data integration and analysis approach is presented and communicated. That is, recent empirical research shows that decision making in complex situations can be influenced by how information is being framed (e.g. de Vries, 2017).

ACKNOWLEDGMENTS

This research was funded by HumanityX, an initiative of the Leiden University's Centre for Innovation.

REFERENCES

Ahmed, Syed, David A. Nelson, et al. "Community engagement for translational disaster research: fostering public, private & responder group partnerships." In Proceedings of the 9th International ISCRAM Conference. Simon Fraser University, Vancouver, Canada, 2012.

Baharmand, H., Boersma, K., Meesters, K., Mulder, F., and Wolbers, J. 2016. "A multidisciplinary perspective on supporting community disaster resilience in Nepal," ISCRAM 2016.

Comes, T., Meesters, K., and Torjesen, S. "Making sense of crises: the implications of information asymmetries for resilience and social justice in disaster-ridden communities." Sustainable and Resilient Infrastructure (2017): 1-13.

Comfort, L. K., Ko, K., and Zagorecki, A. 2004. "Coordination in rapidly evolving disaster response systems: the role of information," *American Behavioral Scientist* (48:3), pp 295-313.

Crowley, J., and Chan, J. 2011. "Disaster Relief 2.0: The Future of Information Sharing in Humanitarian Emergencies, *Harvard Humanitarian Initiative and UN Foundation-Vodafone Foundation-UNOCHA*).

Davis, F. D. 1989. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of. *Management Information Systems Quarterly*, *13*(3), 319–340.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. 1989. User Acceptance of Computer Technology: A Comparison of Two Theoretical Models. *Management Science*, *35*(8), 982–1003.

de Vries, G. 2017. How positive framing may fuel opposition to low-carbon technologies: The boomerang model. Journal of Language and Social Psychology, 36, 28-44.

Delone, W. H., and McLean, E.R. 2003. "The DeLone and McLean model of information systems success: a ten-year update." Journal of management information systems 19(4), 9-30.

Gralla, E., Goentzel, J., & Van de Walle, B. 2015. Understanding the information needs of field-based decision-makers in humanitarian response to sudden onset disasters. In P. L.A., C. T., B. M., & H. A. (Eds.), *Proceedings of the 12th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*.

Gralla, E., Goentzel, J., and Van de Walle, B. 2013. "Field-Based Decision Makers' Information Needs," *Digital Humanitarian Network, Geneva*).

Greenwood, F., Howarth, C., Poole, D., Raymond, N., & Scarnecchia, D. (2017). The Signal Code: A Human Rights Approach to Information During Crisis. Harvard Humanitarian Initiative.

Horita, F., Link, D., Porto de Albuquerque, J., & Hellingrath, B. 2014. A Framework for the Integration of Volunteered Geographic Information into Humanitarian Logistics. In *Proceedings of the Twentieth Americas Conference on Information Systems*.

IATI. (2017). *International Aid Transparency Initiative, Annual Report 2017*.

Janes, A., Sillitti, A., & Succi, G. 2013. Effective Dashboard Design. *Cutter IT Journal*, *26*(1), 17–24.

Janssen, M., Charalabidis, Y., & Zuiderwijk, A. 2012. Benefits, Adoption Barriers and Myths of Open Data and Open Government. *Information Systems Management*, *29*(4), 258–268. https://doi.org/10.1080/10580530.2012.716740

Kapucu, N. 2008. "Collaborative emergency management: better community organising, better public preparedness and response," *Disasters* (32:2), pp 239-262.

Kawasaki, A., Yamamoto, A., Koudelova, P., Acierto, R., Nemoto, T., Kitsuregawa, M., & Koike, T. 2017. Data Integration and Analysis System (DIAS) Contributing to Climate Change Analysis and Disaster Risk Reduction. *Data Science Journal*, *16*(41), 1–17.

Kendra, J. M., and Wachtendorf, T. 2007. "Community innovation and disasters," in *Handbook of disaster research*, Springer, pp. 316-334.

Link, D., Hellingrath, B., & Bültemann, C. 2015. Information Categories for Infrastructure and Logistic Resource Assessments in Humanitarian Logistics. In J. Dethloff, H.-D. Haasis, H. Kopfer, H. Kotzab, & J. Schönberger (Eds.), *Logistics Management* (pp. 445–453). Springer International Publishing.

Maiers, C., Reynolds, M., & Haselkorn, M. 2005. Challenges to Effective Information and Communication Systems in Humanitarian Relief Organizations. In *Proceedings of the International Professional Communication Conference, 2005* (pp. 82–91). IEEE.

Maskrey, Andrew. Disaster mitigation: a community based approach. Oxfam GB, 1989

Mays, R. E., Walton, R., Lemos, M., & Haselkorn, M. (2014). Valuing what works: Success factors in disaster preparedness. An independent analysis of Red Cross/Red Crescent practitioner needs.

Mayunga, J. S. 2007. "Understanding and applying the concept of community disaster resilience: a capital-based approach," *Summer academy for social vulnerability and resilience building* (1), p 16.

Mercer, J., Kelman, I., Taranis, L., & Suchet-Pearson, S. 2010. Framework for integrating indigenous and scientific knowledge for disaster risk reduction. *Disasters*, *34*(1), 214–239.

Morin, V. M., Ahmad, M. M., & Warnitchai, P. 2016. Vulnerability to typhoon hazards in the coastal informal settlements of Metro Manila, the Philippines. *Disasters*, *40*(4), 693–719.

Muhren, W. J., & Van de Walle, B. 2010. A Call for Sensemaking Support Systems in Crisis Management. In R. Babuška & F. C. A. Groen (Eds.), *Interactive Collaborative Information Systems* (pp. 425–452). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-11688-9_16

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., and Pfefferbaum, R. L. 2008. "Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness," *American journal of community psychology* (41:1-2), pp 127-150.

Nur, W., Wan, T., Nor, H., Zakaria, H., and Nazir, M. 2015. "Knowledge sharing and lesson learned from flood disaster: A case in Kelantan," *Journal of Information Systems Research and Innovation* (9:2), pp 1-10.

Onencan, A., Meesters, K., and Van de Walle, B. 2018. "Methodology for participatory gis risk mapping and citizen science for solotvyno salt mines," *Remote Sensing* (10:11), p 1828.

O'Sullivan TL, Kuziemsky CE, Corneil W, Lemyre L, Franco Z. The EnRiCH Community Resilience Framework for High-Risk Populations. PLOS Currents Disasters. 2014 Oct 2 . Edition 1. doi: 10.1371/currents.dis.11381147bd5e89e38e78434a732f17db.

Paulus, D., Meesters, K., & Van de Walle, B. 2018. Turning data into action: supporting humanitarian field workers with open data. In K. Boersma & B. Tomaszewski (Eds.), *Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM)*. ISCRAM.

Piccolo, L. S., Meesters, K., and Roberts, 2018. "Building a Socio-technical Perspective of Community Resilience with a Semiotic Approach," International Conference on Informatics and Semiotics in Organisations, Springer, pp. 22-32.

Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., & Lindgren, R. 2011. Action Design Research. *Management Information Systems Quarterly*, *35*(1), 37–56. https://doi.org/10.2307/23043488

Streefkerk, J. W., Neef, M., Meesters, K., Pieneman, R., and van Dongen, K. 2014. "HCI challenges for community-based disaster recovery," International Conference on Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management, Springer, pp. 637-648.

Sullivan-Wiley, K., & Short Gianotti, A. 2017. Risk Perception in a Multi-Hazard Environment. *World Development*, *97*, 138–152. https://doi.org/10.1016/j.worlddev.2017.04.002

Turoff, M., Chumer, M., Van de Walle, B., & Yao, X. 2004. The design of a dynamic emergency response management information system (DERMIS). *Journal of Information Technology Theory and Application*, *5*(4), 1–35. Retrieved from http://aisel.aisnet.org/cgi/viewcontent.cgi?article=1138&context=jitta

UNOCHA. (2018). Report 2018: The UN's centre for humanitarian data. Retrieved from https://centre.humdata.org/four-takeaways-from-the-centres-first-year/

Van de Walle, B., Brugghemans, B., & Comes, T. 2016. Improving situation awareness in crisis response teams: An experimental analysis of enriched information and centralized coordination. *International Journal of Human Computer Studies*, *95*, 66–79. https://doi.org/10.1016/j.ijhcs.2016.05.001

Van Den Homberg, M., Meesters, K., & Van de Walle, B. 2014. Coordination and information management in the Haiyan response: Observations from the field. *Procedia Engineering*, *78*, 49–51. https://doi.org/10.1016/j.proeng.2014.07.037

Weiss, T. G. 1999. "Principles, politics, and humanitarian action," *Ethics & International Affairs* (13), pp 1-22.

Review-based taxonomy of post-impact volunteerism types to improve citizen integration into crisis response

Robin Batard
Economics, Management and Social Sciences Department, Télécom ParisTech
Industrial Engineering Center, IMT Mines Albi
robin.batard@telecom-paristech.fr

Caroline Rizza
Télécom ParisTech
caroline.rizza@telecom-paristech.fr

Aurélie Montarnal
IMT Mines Albi
aurelie.montarnal@mines-albi.fr

Frédérick Bénaben
IMT Mines Albi
benaben@mines-albi.fr

Christophe Prieur
Télécom ParisTech
christophe.prieur@telecom-paristech.fr

ABSTRACT

Information and Communication Technologies (ICT), and particularly Social Media, drastically changed communication channels and organization during a crisis response. In this context, new forms of citizen initiatives appear, contributing to situational awareness, providing new profiles of stakeholders and broadening the scope of volunteerism in disaster situations. Thus, given the increasing need to understand and take citizen initiatives into account, this article provides a taxonomy of volunteerism types in crisis contexts, based on a literature review on the subject. Mapped on two main dimensions: the *status* (who they are) and the *focus* (what they are doing), multiple types of volunteers are presented on this taxonomy. Then, the article deals with possible use of this taxonomy towards integration of citizen initiatives into the crisis response.

Keywords

Review, Volunteers, Taxonomy, Social Media, Citizen Integration

INTRODUCTION – FROM UNDERSTANDING TO INTEGRATING CITIZENS INTO CRISIS MANAGEMENT PROCESSES

Recent events in France (e.g. 2016 and 2018 floods in Loiret and Aude, 2015 and 2016 terrorist attacks in Paris and Nice) have confirmed the opportunities and challenges raised by social media in crisis management. Ordinary citizens are usually the first on the scene during an emergency to take care of victims, conduct search, organize solutions on-site, and they remain long even after official services have ceased (Whittaker et al. 2015). As citizens are taking a growing place in the stage of crisis management, their voice is strengthened by social media, which has become a tool for them to communicate, organize themselves and act. Moreover, professionals see the increasing potential of social media to address as many people as possible, and to understand citizen behavior during crises. While "real volunteers" and stakeholders are on-site and fight locally against the effects of a crisis, the "virtual volunteers" are located anywhere and help stakeholders on the ground and crisis managers through social media (Reuter et al. 2013).

Volunteerism in crisis management covers a large panel of acceptations, ranging from the most restricted to the broadest. On the one hand, volunteers have been defined as people engaged in response to a request expressly made by a representative of an official organization (Blanchard 2008; Koob and Emergency Management Australia 1998), while on the other hand, we can see volunteerism as any freely chosen and deliberate action, be it spontaneous or organized, which is not necessarily formally regulated (Snyder and Omoto 2008; Wilson 2000; Wolensky 1979). Thus, it appears that between these opposed definitions, there might be a large diversity of volunteerism types, going from the most organized and affiliated to the most spontaneous and unaffiliated.

For example, following the growing place taken by social media in crisis response, some associations such as the Volunteer Operational Support Teams (VOST) and its French equivalent Volontaires Internationaux en Soutien Opérationnel Virtuel (VISOV) appeared. Progressively, they are playing an intermediary role between ordinary citizens and official crisis managers by filtering and processing social media data to help improving the situational awareness in real time. Although in France, the VISOV are becoming more and more institutionalized by signing agreements with official crisis response partners, they remain an association, and they are just an example amongst a growing number of diverse and varied citizen initiatives based on the great potential of ICT in crisis response.

To make the most of this potential help and support for crisis response, there is definitely a need for integration of social media in IT for crisis management (Mathioudakis and Koudas 2010; Vieweg et al. 2010). Moreover, it is essential for local authorities to recognize that in times of crisis, unsolicited volunteers will show up (der Heide 2003) and to date, there is a lack of frameworks to create a comprehensive and manageable process to ensure the most effective and safe response with the aid of spontaneous volunteers (Orloff 2011).

The research presented in this paper, conducted as part of the French National Research Agency project MACIV (Management of Citizens and Volunteers: the social media contribution in crisis situations), focuses on the diversity of citizen initiatives as they are fostered by social media in times of crisis, to understand them, and think about ways to integrate them into crisis response and management processes. In order to understand this diversity of citizen initiatives and to propose ways to integrate them into crisis response and management processes, the research is divided into two lines, which can be presented as follows:

1. Understanding the role played by citizens in times of crisis to foster organizational collaboration with official responders
2. Proposing an IT solution to orchestrate the collaboration between professionals and citizens in real-time

In this article, we will present the first research findings related to the first axis, as a requirement for the second one.

Indeed, when it comes to integrating citizens into crisis management processes (2.), the first need that rises is about understanding citizens taking part in a crisis response (1.). To answer to this question, the first step presented in this article consists in understanding who these citizens are, by creating a taxonomy of volunteerism types in crisis response and management. Then, the idea will be to describe the likelihood of the appearance of each type of volunteerism, depending on the crisis context, i.e. the disaster type, its extent, and the environment type. In this article, we argue that if we are able to categorize the citizens in times of crisis, and to give their characteristics, then we could be able to identify them when a crisis occurs. Then, we could go into further details to understand the way they are acting: what are the communication, organization and action processes that these types of volunteers put into practice to address their needs or those of the community? Given an advanced knowledge of these types of volunteers, and looking through the prism of social media, crisis responders could then be able to identify volunteer types, understand them, and take decisions regarding whether or not to integrate them into the crisis response process.

The final goal of this research would be to integrate citizen initiatives in times of crisis into a suite of tools to support collaboration in crisis management: RIO-Suite. This software, based on a generic model of collaboration, aims to instantiate every concept that can potentially take part in a crisis occurrence (environment, dangers, risks, opportunities, threats, partners, competences, resources, stakes…), to then propose an optimized plan to orchestrate the crisis response in real-time. Thus, the taxonomy of volunteer types presented in this paper will be a first step to implement the integration of citizens into RIO-Suite, but it has been created without any consideration of the software framework to remain useful for other research purposes dedicated to understand citizens engaged in crisis response.

HISTORY AND EVOLUTION OF VOLUNTEERISM IN CRISIS SITUATIONS

What does *volunteerism* mean?

Derived from the Middle French[1] word *voluntaire*, the noun *volunteer* was first used as "one who offers himself for military service" (c. 1600)[2]. Then, over time, the concept evolved beyond the military framework, to include broader forms of engagement. Described by Dynes (1970) as an "expansion of the citizenship role", volunteerism has become a vast concept with unclear boundaries.

[1] Middle French is the first form of official unified French language in the kingdom of France (14th – 17th centuries)
[2] ("volunteer | Origin and meaning of volunteer by Online Etymology Dictionary" 2019)

After reviewing several definitions, Cnaan et al. (1996) conclude that the boundaries of the term *volunteer* vary from one context to the other. They show that widely used definitions of the term range from the broadest to the purest of interpretations. According to their results, definitions vary on four key dimensions: free will, remuneration, intended beneficiaries and structure.

We can find back three of these four dimensions in the requirements of volunteerism according to the United Nations Development Programme (UNDP): "Firstly, the action should be carried out voluntarily, according to an individual's own free will, [...] Secondly, the action should not be undertaken primarily for financial reward. [...] Thirdly, the action should be for the common good. [...] The three criteria of free will, non-pecuniary motivation, and benefit to others can be applied to any action to assess whether it is volunteerism." (United Nations and EBSCOhost 2011) In this definition, the UNDP voluntarily puts aside the notion of "mandatory volunteerism" such as community service as an alternative to military duty or custodial sentences. The report also states that it doesn't consider the organizational criterion (i.e. "structure" in (Cnaan et al. 1996)) in the definition, in order to include many acts of volunteerism that take place outside of a formal context. This is in line with Whittaker et al.'s (2015) argument, who after having compared several definitions, argues that many of them "exclude those who act independently of the state or formal organisations, and obscure much of the shorter-term, informal volunteering that occurs in times of crisis." Thus, they defend the idea that "less rigid definitions of volunteerism are needed to fully recognise and value citizen contributions in the context of emergency and disaster management." (Whittaker et al. 2015)

Thus, the notion of volunteering has expanded over the years, and the field of crisis management has seen the emergence of initiatives that have pushed the boundaries of the term. In its most inclusive sense, volunteerism in crisis management can be defined as 'any willful action, be it spontaneous or organized, carried out outside the actor's working context, in which time is given to benefit another person, group or organization'.

Social Media: shifting paradigms in crisis management

Social media, and in general, Information and Communication Technologies (ICT) have drastically changed the way a crisis is managed, both on social and technical aspects. On one side, they foster inter-organizational communication, and give a voice to citizens. On the other side, they provide powerful tools for crisis responders to improve their situational awareness. Among the profusion of literature on the subject, we can quote Kietzmann et al. (2011) who identified seven functional blocks of social media (Identity, Conversations, Sharing, Presence, Relationships, Reputation and Groups), and state that every social media tool focuses on some of these blocks. In a crisis-related situation, Alexander (2014) lists some functions for which social media can be used, such as listening, monitoring, searching, crowdsourcing, creating social cohesion or furthering causes.

While traditional communication between citizens and professionals used to be "from one to one", social media are shifting paradigms, and making crisis management a many-to-many communication system. Sometimes being alternative channels, sometimes even backchannels, they play an essential role in crisis response and management, both on professionals and volunteer sides (Sutton et al. 2008). Based on Reuter et al.'s (2011) communication matrix for a social software infrastructure (see Table 1), Grant et al. (2013) state that social media can play an important role for crisis management at operational and tactical levels between organizations.

Table 1. Reuter et al.'s (2011) communication matrix for a social software infrastructure

Receiver / Sender	**Organizations**	**Citizen**
Organization	Inter-organizational crisis management	Citizen communication
Citizen	Integration, aggregation and validation of citizen-generated content	Self-help communities

Whether it is online or offline, official crisis responders know that citizens will always act during a crisis event. The very structure of communication and information sharing dynamics is changing both for emergency managers and the public (Alexander 2014). Thus, there is a value for both professionals and citizens to become aware of others' needs and behaviors, and contribute together to situational awareness.

Between citizens on the ground acting on different forms within different social structures, and citizens using social media to provide and organize information about the situation, there is a large range of crisis-related volunteerism types. From a volunteer firefighter acting within an official organization and receiving a

remuneration, to an individual spontaneous unaffiliated citizen using Twitter to share an information, volunteerism in crisis situations include a wide range of initiatives that we will need to classify if we want to think about integrating them into crisis management processes.

Categorizing the different forms of volunteerism in crisis situations

Based on previous work by Quarantelli (1966), the Disaster Research Center (DRC) at Ohio State University focused on the type of structure taking part to the response (old or new) and the type of tasks undertaken by the responders (regular or non-regular) to propose a first typology of organized response to disasters, presented in Table 2.

Table 2. The DRC typology of organized response to disasters (Dynes 1970)

	Regular tasks	**Non-regular tasks**
Old structure	Type I: Established	Type III: Extending
New structure	Type II: Expanding	Type IV: Emergent

Although today's crises are mainly managed by official organizations, it seems that spontaneous volunteerism is the first form of crisis management in history. Indeed, people spontaneously helped each other long before creating organizations to do so. (Orloff 2011) Thus, we can expand the DRC typology to other forms of volunteerism that appear outside of organizations. Stallings and Quarantelli (1985) define emergent groups as "private citizens who work together in pursuit of collective goals relevant to actual or potential disasters but whose organization has not yet become institutionalized." These groups include a more specific type: *spontaneous volunteerism*: "people who offer assistance following a disaster and who are not previously affiliated with recognized volunteer agencies and may or may not have relevant training, skills or experience" (Cottrell 2010). Although emergent volunteerism can appear at any phase of the crisis cycle, spontaneous volunteers are a specific form of volunteerism that only appears in the response phase, once a crisis occurs. (Whittaker et al. 2015)

Based on this distinction between anticipated and spontaneous volunteers, and distinguishing the volunteerism whether it is within an organization or not, Shaskolsky (1965) proposes four different types of volunteerism, with examples to illustrate the four cases. See Table 3.

Table 3. Examples of the different types of volunteerism (Shaskolsky 1965)

	Individual	**Organized**
Anticipated	Doctor	Regular volunteer firefighter
Spontaneous	Search and rescue by bystander	Non-regular volunteer firefighter

As presented by Cnaan et al. (1996), the intended beneficiaries, i.e. the interests that the volunteer has in mind, are also a criteria to take into account. Based on the opposition between altruism and egoism, described by Durkheim (1933 p. 198) as "two sides of conduct [that] are found present from the beginning in all human consciences", Wolensky (1979) distinguishes the motivations of volunteers between public and private interests, to present four types of "post-impact" volunteerism in Table 4.

Table 4. The four types of "post-impact" volunteerism (Wolensky 1979)

Social Form / **Motivation**	**Emergent**	**Organizational**
Public Interests	Altruistic	Communalistic
Private Interests	Egoistic	Mutualistic

Here are some insights regarding these volunteers' motivations:

- **Altruistic volunteers** have a genuine concern for human safety and neighborly aid;
- **Egoistic volunteers** put their private interests before those of the community;
- **Communalistic volunteers**' action is aimed at the entire community, its members and their problems;
- **Mutualistic volunteers** provide help primarily to fellows sharing common characteristics.

PROPOSAL – CATEGORIZING VOLUNTEER TYPES TO FOSTER CITIZEN INTEGRATION

When looking at the several attempts to classify the different forms of volunteerism, it appears that different dimensions are used. The Table 5 below presents the previously-used dimensions to categorize volunteerism types, their semantic equivalents, and corresponding references.

Table 5. The various dimensions that have been used to distinguish between volunteerism types

id	Dimension	Equivalents	Examples in literature
1	Affiliated / Unaffiliated	Formal / Informal; Official / Unofficial; Organized / Individual; Organizational / Emergent; Old / New Structure	(Cnaan et al. 1996; Dynes 1970; Shaskolsky 1965; Whittaker et al. 2015; Wolensky 1979)
2	Action / Information	Real / Virtual; On-site / Online	(Reuter et al. 2013)
3	Skilled / Unskilled	Regular / Non-regular tasks	(Dynes 1970)
4	Anticipated / Spontaneous		(Shaskolsky 1965; Whittaker et al. 2015)
5	Public interests / Private Interests	Intended beneficiaries: Others / Relatives / Oneself	(Cnaan et al. 1996; Wolensky 1979)
6	Remuneration: None / None expected / Expenses reimbursed / Stipend, low pay		(Cnaan et al. 1996)
7	Free will / Relatively uncoerced / Obligation		(Cnaan et al. 1996)

As showed before, volunteerism is a broad concept. Thus, the classification dimensions depend on the angle of view from which the concept is viewed (i.e. from which stakeholder we want to understand volunteerism) and on the filter that is placed on the lens (i.e. the objective we have in mind). Indeed, the research goal here is not to decide whether or not a citizen behavior should be considered as volunteerism, as it was for Cnaan et al. (1996), but to help official crisis responders to take decisions regarding whether or not a citizen initiative should be integrated to the crisis response.

To do so, the first categorization dimension that seems essential, and present in almost every literature, is the social structure in which the citizen initiative takes place (1). Although the term and its meaning are not exactly the same in every reference ("structure" for Cnaan et al. and Dynes; "organization" for Shaskolsky, Wolensky and Whittaker et al.), it appears that every author deals with the formalism level of the citizen's social structure.

Secondly, it is important to make a distinction between information and action (2). As Reuter et al. (2013) stated, whereas "real" volunteers are directly acting on the ground, "virtual" ones provide information about the situation, and help to understand what happens on the ground. In that sense, whereas citizens' will and ability to act in times of crisis have always been present, the emancipation of ICT, and in particular social media, has disrupted the construction and circulation of information during a crisis event.

Thus, given a volunteer initiative, the two first questions we want to answer are the following:

- **Who?** Are these citizens acting by themselves, in group, or are they registered within an organization? This volunteer initiative's social structure will be called *Status*.
- **What?** Are these volunteers focused on improving the situational awareness thanks to information, or are they focused on the action on the ground? This dimension will be called *Focus*.

Although the skill level (3) is an essential criterion for crisis responders to take decisions about whether or not to integrate a volunteer initiative, it doesn't appear as a convincing criterion to distinguish two volunteers in a taxonomy. Indeed, amongst the unaffiliated volunteers, each can be divided in two sub-categories depending on the skill level for this specific task. Thus, the skill level can be seen as a third dimension in the taxonomy, whether it is a binary or continuous axis, and knowing it given a citizen initiative, it could help the decision taking regarding this volunteer. In addition, the boundary between dimension "Skilled / Unskilled" (3) and dimension "Anticipated / Spontaneous" (4) is thin. Indeed, if we look at Shaskolsky's interpretation, we can consider that a citizen having skills for a specific task will be considered as an anticipated volunteer to do it, whereas a citizen acting without any skill regarding the task he/she is doing will be considered spontaneous for this task. In this way, a third dimension in the taxonomy could join these two aspects (dimensions 3 and 4) as a degree of the volunteer's inclination to help.

Given the integration objective, it doesn't appear to be useful to take into account several dimensions of the Table 4 above, such as the remuneration (6), or the free will (7), which were dimensions used to identify if a given behavior should be considered as volunteerism or not. Finally, regarding the interests (5), further discussions with crisis management stakeholders will need to be done to state about the relevance of this dimension.

A two-dimension taxonomy of volunteerism types: Status and Focus

When dealing about the volunteers' status, the main distinction that appears is about the degree of formalism of the volunteer initiative, which we divided in four levels:

- **Individual volunteers** are citizens taking decisions by themselves regarding their behavior in the crisis management;
- **Group volunteers** are citizens acting together and taking common decisions to address specific needs;
- **Organized volunteers** are citizens officially affiliated to an organization or registered through an application;
- **Formalized volunteers** are organized volunteers whose organization or application has been officially recognized by crisis responders.

Regarding the focus, we divided the volunteers depending on if they are focused on information or on action. This is an equivalent of what Reuter (2013) called "virtual" and "real" volunteers, but considering that even citizens using traditional communication channels (e.g. phone calls) are considered as "information volunteers". Thus, we identified four types of focus:

- **Organizing information** are volunteers focused on the information filtering, analysis and organization to provide an insight on the crisis situation;
- **Sharing information** are volunteers using the communication tools in their possession (social media, phone…) to spread information that might help to improve situational awareness;
- **Managing action** are volunteers that take decisions regarding who should do what, to assign tasks to other stakeholders;
- **Doing action** are volunteers carrying out actions on the ground.

Given these two dimensions, the Figure 1 presents different examples of volunteerism, depending on the level of status and the type of focus.

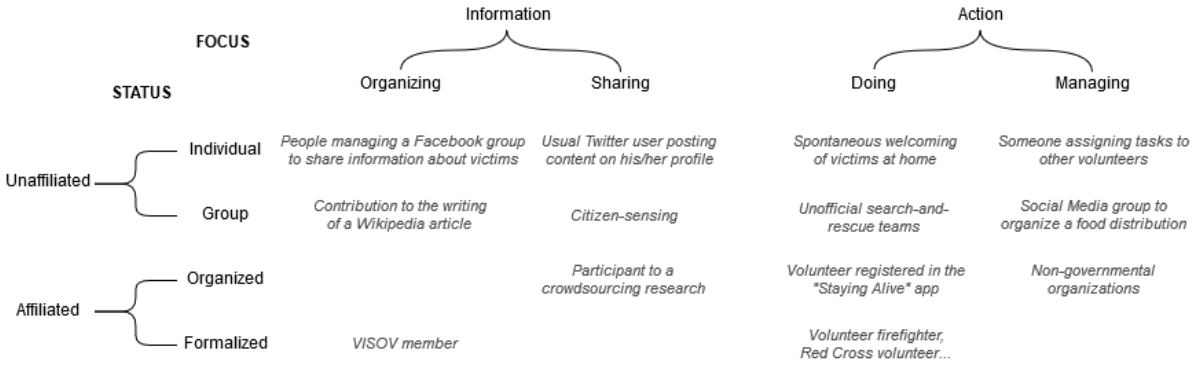


Figure 1. Taxonomy of volunteerism types with examples

One interesting example is the status of the VISOV association in France. Indeed, the association started with a group of people looking at social media in times of crisis to find useful information and share it with the crisis responders. It then became an association, and progressively signed agreements with official crisis management institutions in France, such as the Ministry of the Interior or several regional fire brigades, becoming then a formalized association. Now, when an important event happens, the VISOV are 'activated' as an official intermediary organization between citizens and crisis responders.

Moreover, in this matrix, we can find some groups of volunteers identified in previous literature, as presented in Figure 2. For example, any volunteer focused on sharing information is providing *User-Generated Content (UGC)*, which is "media content that is created or produced by the general public rather than by paid professionals and is primarily distributed on the Internet." (Daugherty et al. 2008) A sub-category of UGC is the *Volunteered Geographic Information (VGI)* (Goodchild 2007; Zook et al. 2010): "spatial data that are produced and disseminated by individuals or non-official institutions, i.e. by ordinary citizens using appropriate tools to gather and disseminate their views and geographical knowledge on the web" (Horita et al. 2013). As another example, on this map of volunteer types, we find the Intermediary Organizations, described by Zettle et al. (2017) as "a voluntary association of individual and/or collective civil society actors and acts as an intermediary between public authorities and the civil society."

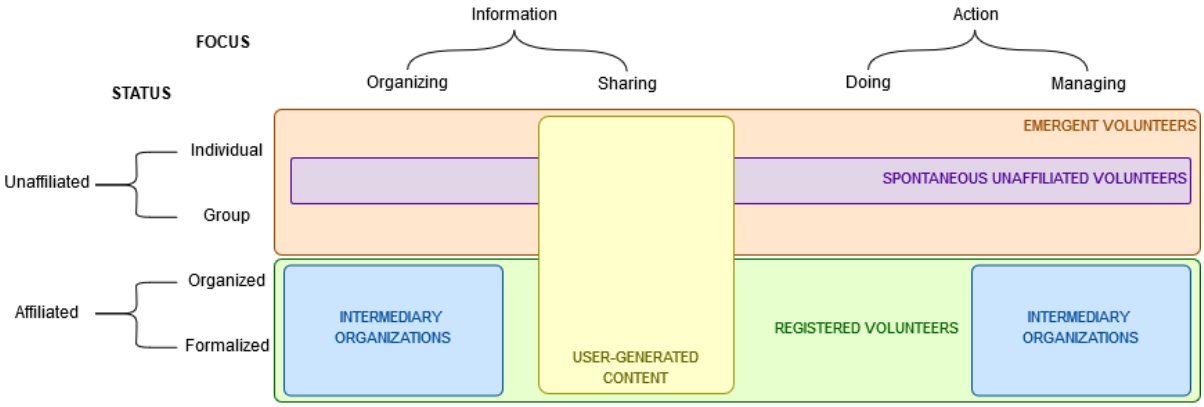


Figure 2. Different forms of volunteerism represented within the frame of the taxonomy

Towards integration of volunteerism into crisis management processes

The first thing that we can notice about this taxonomy is that the *status* axis can be seen as a degree of reliability of the citizen initiative. As official responders communicate closely with formalized organizations during the crisis response, it becomes more difficult for them to integrate those at the lower level of the status axis, i.e. the individual unaffiliated volunteers.

If we look at the *focus* axis, considering the current situation in France, and based on exploratory interviews we have conducted with crisis responders (from the Ministry of Interior and the Var region fire brigade), it appears that professionals tend to pay attention in priority to forms of volunteerism that focus on organizing information, such as VISOV. As the crisis gets worse, they will progressively broaden their attention to raw information shared by citizens. Then, in extreme cases, they will think about integrating less formal volunteers managing and doing actions on the ground. Indeed, for professionals, integrating volunteers to the response is risky. Firstly, when it comes to integrating information provided by citizens, especially from social media, several challenges appear,

regarding data quality, trust and format, and social media can lead to rumor propagation, panic, or rise new ethical challenges (Alexander 2014; Crawford and Finn 2015; Rizza and Pereira 2014). Secondly, interviews we have conducted with crisis responders show that integrating citizen action remains the most challenging part for professionals. Whether it is about supporting or just letting the action being done by a citizen is for professionals a risk of endangering an individual whose own objective should be his/her own safety.

Last but not least, first discussions with official crisis responders, volunteers and researchers in the field tend to indicate that as the crisis situation becomes more complex, the professionals' decision-making process tends to be disturbed because of stress, uncertainty, time pressure, heightened public scrutiny and cognitive overload, which could result in tunnel vision and information bias (Cao et al. 2008; Schraagen and van de Ven 2008; Svedin 2011). Thus, in a highly chaotic crisis, we can assume that a large range of volunteerism types will be present, bringing a lot both on the action or on the information side, but the professionals might close their cooperation doors to focus on a small range of tasks they have to accomplish with partners they already know.

Given these considerations, we make the assumption that there are different levels of severity of the crisis at which it could be relevant for professionals to take citizen initiatives into account. The more complex the crisis, the more diverse the citizen initiatives will be. At the same time, it should be considered that the more complex the crisis, the more opportunities professionals will have to integrate these initiatives, starting with the most formalized and information-focused ones, and progressively opening their mind to less formal, more spontaneous and action-focused initiatives. Thus, based on the taxonomy presented before, we can develop a map of levels of opportunities of volunteer consideration in the crisis response, depending on the severity of the situation (i.e. the "degree of chaos"). This map is presented in Figure 3.

Note that in this hypothesis, the "degree of chaos" is a notion that might rely on a diversity of parameters that can affect the complexity of the situation. As a first attempt to specify this *degree of chaos*, the influencing parameters could be the crisis type, its duration, the variety and volume of the needs professionals have to address, the professionals' competences and resources, the ethical, legal and social aspects regarding the integration of a citizen, or the risk that this integration might represent. The *degree of chaos* can be seen as an extension of Franco et al's "disaster impact index" (2008), and further research is needed to clarify this concept.

Future research will be conducted to refine the parameters influencing these opportunities, and to understand professionals' needs, to help them converting an opportunity into a concrete integration of an initiative.

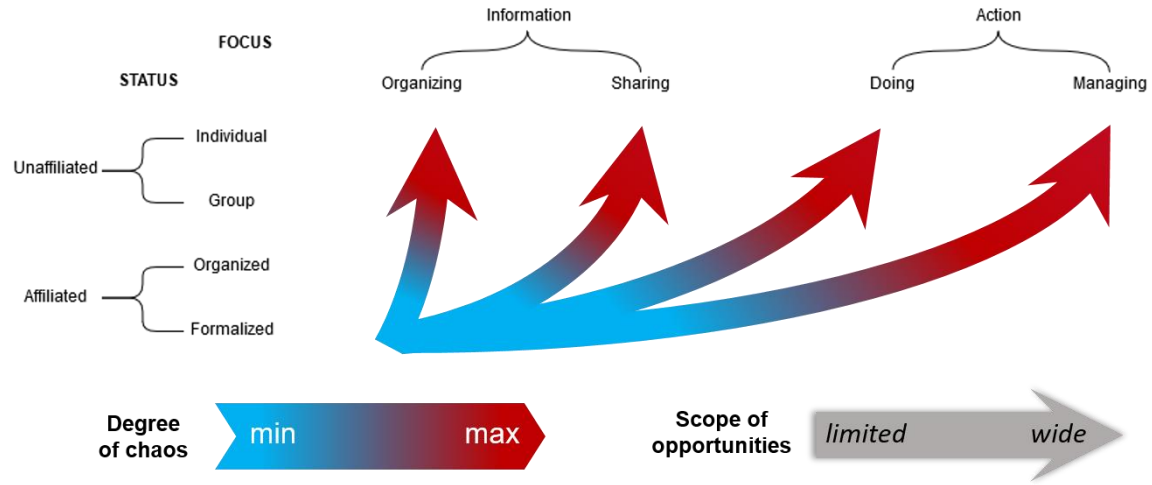


Figure 3. Scope of opportunities of volunteer consideration by professionals, regarding the degree of chaos of the crisis

ANALYSIS AND DISCUSSION

Regarding the taxonomy itself, one important dimension that doesn't appear is the skill level of the volunteer regarding the action he or she is doing (i.e. *regular* / *non-regular tasks* (Dynes 1970)), combined with the spontaneity of the initiative. As presented before, these parameters could be joined as a third dimension in the taxonomy, representing the volunteer's inclination to help.

Having in mind the goal of integrating citizen initiatives, or at least be aware of them during a crisis response, it could be relevant to think about prioritizing the volunteerism forms that might be relevant to take into account.

To do so, other interviews will be conducted with official crisis management stakeholders, to understand their needs regarding the understanding of citizen behaviors. In addition, it could be relevant to identify the likelihood of the presence of the several types of volunteers in each kind of crisis, in each kind of environment, to complete the official responders' needs and help to prioritize the focus on several volunteerism types. Specifying the decision-makers' needs could also help to dispel their tunnel vision and cognitive overload by providing relevant advice, and thus make them more open to the integration of new initiatives.

Moreover, developing a taxonomy is always a risky exercise, as it should be kept in mind that the objective is to help the understanding of the types of volunteerism to help the professionals' decision taking, and not to lose the subtlety of human behavior by putting a label on a volunteer profile. Thus, given a citizen initiative, the only fact of identifying its status, its focus, or its skill level will not be comprehensive enough to describe precisely this initiative. In future research, more details will need to be provided regarding this initiative, based on the professionals' needs.

As volunteerism is a constantly evolving concept, it is important to remain aware that the diversity of volunteerism types will evolve as quickly as the crisis will do. The inventiveness and improvisation of citizens in times of crisis might always bring to the light unpredictable types of volunteers. Thus, whatever method is used to understand and integrate citizen initiatives, it must be sufficiently inclusive not to close the door to these emerging forms of volunteerism.

CONCLUSION

Resulting from a diversification of citizen initiatives thanks to the development of social media, volunteerism in crisis situations is a vast concept that official crisis responders need to comprehend in order to improve their situational awareness, and at the same time, their response to the crisis. The taxonomy of volunteerism types presented in this article is mainly based on a literature review regarding volunteerism in crisis situations, and previous attempts of categorizing the volunteers.

Given the objective to provide crisis responders an insight on what citizens are doing during a disaster, this article presents a two-dimension matrix of volunteerism types. The first dimension – the *status* – aims to identify the social structure in which the initiative takes place, going from an individual unaffiliated behavior to an affiliated, organized and officially recognized initiative. The second dimension – the *focus* – is dedicated to the type of initiative, depending on whether it concerns *information* that can improve the situational awareness, or *action*, which has a direct impact on the ground.

Future interviews and field observation will be conducted with official crisis responders to refine their needs regarding the understanding of citizen initiatives, and thus to refine the taxonomy presented in this article. For example, having more details regarding the skill level, the spontaneity, or even the motivation of citizen initiatives might be relevant parameters for the professional's point of view.

To make use of such a taxonomy, the research can then think about the parameters that can influence the professionals' decision making regarding the integration of a citizen initiative. As an example, based on exploratory interviews conducted with official crisis responders, this paper presents the idea of a hypothetic "degree of chaos" which might rely on a diversity of parameters linked to the crisis situation, and that might be deterministic for professionals' decision about taking into account or not this or that citizen initiative. However, the information overload faced by crisis managers in complex situations reminds that there is a significant gap between having the opportunity to integrate an initiative, and concretely integrating it.

As the decision making in crisis centers relies mainly on the information professionals have, the next steps in this research project will be to conduct interviews with both professionals and volunteers in order to 1) understand professionals' needs regarding the understanding of volunteers; 2) present a comprehensive map of volunteers' contribution in crisis situations and 3) find relevant information to provide to the crisis responders regarding the real-time citizen initiatives, and help them to take decisions about their integration.

REFERENCES

Alexander, D. E. (2014). "Social Media in Disaster Risk Reduction and Crisis Management." *Science and Engineering Ethics*, 20(3), 717–733.

Blanchard, B. W. (2008). "Guide to emergency management and related terms, definitions, concepts, acronyms, organizations, programs, guidance, executive orders & legislation." 1366.

Cao, Y., Nijholt, A., Theune, M., Sluis, van der, I., Bachvarova, Y., and Andre, E. (2008). *Modality planning for preventing tunnel vision in crisis management*. The Society for the Study of Artificial Intelligence and Simulation of Behaviour.

Cnaan, R. A., Handy, F., and Wadsworth, M. (1996). "Defining Who Is a Volunteer: Conceptual and Empirical Considerations." *Nonprofit and Voluntary Sector Quarterly*, 25, 364.

Cottrell, A. (2010). *Research Report: a survey of spontaneous volunteers*. Report, Australian Red Cross.

Crawford, K., and Finn, M. (2015). "The limits of crisis data: analytical and ethical challenges of using social and mobile data to understand disasters." *GeoJournal*, 80(4), 491–502.

Daugherty, T., Eastin, M. S., and Bright, L. (2008). "Exploring Consumer Motivations for Creating User-Generated Content." *Journal of Interactive Advertising*, 8(2), 16–25.

Durkheim, E. (1933). "The Division Of Labor In Society." 462.

Dynes, R. R. (1970). *Organized Behavior in Disaster*. Heath Lexington Books.

Franco, Z. E., Zumel, N., Blau, K., Johnson, K. A., and Beutler, L. E. (2008). "Causality, covariates and consensus in ISCRAM research: towards a more robust study design in a transdisciplinary community." *International Journal of Emergency Management*, 5(1/2), 100.

Goodchild, M. F. (2007). "Citizens as sensors: the world of volunteered geography." *GeoJournal*, 69(4), 211–221.

Grant, T. J., Geugies, F. L. E., and Jongejan, P. A. (2013). "Social Media in Command & Control: A proof-of-principle experiment." *Proceedings of the 10th International Conference on Information Systems for Crisis Response And Management*, 10.

der Heide, E. A. (2003). "Convergence behavior in disasters." *Annals of Emergency Medicine*, 41(4), 463–466.

Horita, F. E., Degrossi, L., Assis, L. F. de, Zipf, A., and Albuquerque, J. P. de. (2013). "The use of Volunteered Geographic Information (VGI) and Crowdsourcing in Disaster Management: a Systematic Literature Review." *AMCIS 2013 Proceedings*.

Kietzmann, J. H., Hermkens, K., McCarthy, I. P., and Silvestre, B. S. (2011). "Social media? Get serious! Understanding the functional building blocks of social media." *Business Horizons*, 54(3), 241–251.

Koob, P., and Emergency Management Australia. (1998). *Australian emergency management glossary*. Emergency Management Australia, Dickson, A.C.T.

Mathioudakis, M., and Koudas, N. (2010). "TwitterMonitor: trend detection over the twitter stream." *Proceedings of the 2010 international conference on Management of data - SIGMOD '10*, ACM Press, Indianapolis, Indiana, USA, 1155.

Orloff, L. (2011). *Managing Spontaneous Community Volunteers in Disasters: a field manual*. CRC Press.

Quarantelli, E. L., Ohio State University, and Disaster Research Center. (1966). *Organization under stress*. Disaster Research Center, the Ohio State University, Columbus, Ohio.

Reuter, C., Heger, O., and Pipek, V. (2013). "Combining Real and Virtual Volunteers through Social Media." *Proceedings of the 10th International Conference on Information Systems for Crisis Response And Management*, 11.

Reuter, C., Marx, A., and Pipek, V. (2011). "Social Software as an Infrastructure for Crisis Management - a Case Study About Current Practice and Potential Usage." *Proceedings of the 8th International Conference on Information Systems for Crisis Response And Management*, 10.

Rizza, C., and Pereira, Â. G. (2014). "Building a resilient community through social network: ethical considerations about the 2011 Genoa floods." *Proceedings of the 11th International Conference on Information Systems for Crisis Response And Management*, 6.

Schraagen, J. M., and van de Ven, J. G. M. (2008). "Improving Decision Making in Crisis Response Through Critical Thinking Support." *Journal of Cognitive Engineering and Decision Making*, 2(4), 311–327.

Shaskolsky, L. (1965). "Volunteerism in disaster situations." 43.

Snyder, M., and Omoto, A. M. (2008). "Volunteerism: Social Issues Perspectives and Social Policy Implications." *Social Issues and Policy Review*, 2(1), 1–36.

Stallings, R. A., and Quarantelli, E. L. (1985). "Emergent Citizen Groups and Emergency Management." *Public Administration Review*, 45, 93.

Sutton, J., Palen, L., and Shklovski, I. (2008). "Backchannels on the Front Lines: Emergent Uses of Social Media in the 2007 Southern California Wildfires." *Proceedings of the 5th International Conference on Information Systems for Crisis Response And Management*, 9.

Svedin, L. (2011). *Ethics and Crisis Management*. IAP.

United Nations, and EBSCOhost. (2011). *State of the World's Volunteerism Report 2011: Universal Values for Global Well-being*. United Nations Publications National Book Network, New York; Blue Ridge Summit.

Vieweg, S., Hughes, A. L., Starbird, K., and Palen, L. (2010). "Microblogging during two natural hazards events." *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, 1079.

"volunteer | Origin and meaning of volunteer by Online Etymology Dictionary." (2019). <https://www.etymonline.com/word/volunteer> (Jan. 18, 2019).

Whittaker, J., McLennan, B., and Handmer, J. (2015). "A review of informal volunteerism in emergencies and

disasters: Definition, opportunities and challenges." *International Journal of Disaster Risk Reduction*, 13(Supplement C), 358–368.

Wilson, J. (2000). "Volunteering." *Annual Review of Sociology*, 26(1), 215–240.

Wolensky, R. P. (1979). "Toward a Broader Conceptualization of Volunteerism in Disaster." *Journal of Voluntary Action Research*, 8(3–4), 33–42.

Zettl, V., Kotthaus, C., Ludwig, T., and Skudelny, S. (2017). "Embedding Unaffiliated Volunteers in Crisis Management Systems: Deploying and Supporting the Concept of Intermediary Organizations." *Proceedings of the 14th International Conference on Information Systems for Crisis Response And Management*, 11.

Zook, M., Graham, M., Shelton, T., and Gorman, S. (2010). "Volunteered Geographic Information and Crowdsourcing Disaster Relief: A Case Study of the Haitian Earthquake." *World Medical & Health Policy*, 2(2), 7–33.

Track 12.

Tool Talks

Chairs,

Bas Linjse, *Radboud University, Netherlands*

Jürgen Moßgraber, *Fraunhofer IOSB, Germany*

Anastasios Karakostas, *Centre for Research and Technology Hellas*

Management of Sensor Data with Open Standards

Philipp Hertweck
Fraunhofer IOSB
philipp.hertweck@iosb.fraunhofer.de

Tobias Hellmund
Fraunhofer IOSB
tobias.hellmund@iosb.fraunhofer.de

Hylke van der Schaaf
Fraunhofer IOSB
hylke.vanderschaaf@iosb.fraunhofer.de

Jürgen Moßgraber
Fraunhofer IOSB
juergen.mossgraber@iosb.fraunhofer.de

Jan Blume
Fraunhofer IOSB
jan-wilhelm.blume@iosb.fraunhofer.de

ABSTRACT

In an emergency, getting up-to-date information about the current situation is crucial to orchestrate an efficient response. Due to its objectivity, preciseness and comparability, time-series data offer broad possibilities to manage emergency incidents. Since the Internet of Things (IoT) is rapidly growing with an estimated number of 30 billion sensors in 2020, it offers excellent potential to collect time-series data for improving situational awareness. The IoT brings several challenges: caused by a splintered sensor manufacturer landscape, data comes in various structures, incompatible protocols and unclear semantics. To tackle these challenges a well-defined interface, from where uniform data can be queried, is necessary. The Open Geospatial Consortium (OGC) has recognized this demand and developed the SensorThings API standard, an open, unified way to interconnect devices throughout the IoT, which is implemented by the **FR**aunhofer-**O**pensource-**S**ensor**T**hings-Server (FROST). This paper presents the standard, its implementation and the application to the domain of crisis management.

Keywords

Sensor data management, Time-series data, Data storage and retrieval, Open-source software, SensorThings API, OData, REST, MQTT, FROST

INTRODUCTION

The situational awareness of emergency managers relies on up-to-date and correct information. One possibility to retrieve most accurate and objective data is the utilization of sensors collecting time-series data, for example water levels of a river, wind speed or temperature. Monitoring a single sensor alone might not offer much benefit; however, the monitoring of many sensors targeted at a linked causality brings valuable insights. If these sensors are connected to a network, one speaks of the Internet of Things (IoT), which is rapidly growing: due to narrow production costs and huge potential in the field (Lee & Lee, July-August 2015), more than 30 billion connected IoT-devices are expected in 2020, growing to 75 billion devices in 2025 (Statista.com, 2019). One of the most promising prospects of IoT is the comparatively simple collection of vast amounts of data. Through a large number of devices monitoring different natural phenomena, an unlike larger amount of data can be collected. Still, since several different manufacturers produce these devices, the access to data is hindered through different data models and access protocols. In detail, data coming from IoT-devices is characterized through several traits. Firstly, the data comes from different sources and is heterogeneous, it is unstructured and without clear semantics. Without preprocessing, the data is not interoperable in the first place. Secondly, the large number of devices causes a mentionable amount of data that requires an annotation with metadata, which provides semantic information, to make them reusable. Lastly, the flexibility of IoT devices allows the collection of data at different points in time at different places offering spatial-temporal correlations (Li, Liu, Tian, Shen, & Mao, 2012).

The Open Geospatial Consortium (OGC) has recognized these challenges and developed the SensorThings API. It is a standard for the collection, storage and retrieval of time-series data. The data can be collected through IoT-devices, but it is not limited to these: the number of available sand packs during a flood event at a specific location or the number of manufactured items in a production line could be collected through other devices and subsequently be integrated, too. The standard defines a model for sensor data and its metadata, as well as an interface for both data storage and retrieval. The service can be queried with powerful filters, including geospatial search possibilities. The goal of the SensorThings API is to offer a unified way for the usage of sensor-data and to facilitate the development of data-driven applications. The Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB adopted this standard and has developed an open-source Java implementation of the SensorThings API. This implementation, called FROST, is fully compliant to the standard and certified by the OGC. FROST has been deployed in several projects where it forms the single point of managing time-series data.

This paper introduces the OGC SensorThings API in detail; explains the data model, the query options and interfaces. Subsequently, the FROST implementation and supplementary software is introduced. In a further section, it presents two EU-funded projects located in the domains of Climate Change and Crisis Management, in which FROST was successfully applied. Before the conclusion, a short passage highlights further developments and the relevance of this research.

RELATED WORK

The Sensor Observation Service (SOS) bases, like the SensorThings API on the OGC Observations and Measurements standard (O&M). It is, just like the SensorThings API a standard of the OGC and has been published in 2012 (Open Geospatial Consortium, 2012). It defines a web service interface, which allows querying observations, sensor metadata and representations of observed features. It defines means to register new sensors and remove obsolete sensors. The interface is realized by using the Simple Object Access Protocol (SOAP). The data itself is encoded in the Extensible Markup Language (XML). SOS offers at least three service operations: *GetCapabilities*, *GetObservation* and *DescribeSensor*, whereas the first will retrieve a description of SOS itself, describe further operations (if available) and state what kind of measurements are recorded. The second will retrieve specific observations and their metadata. The third gives explicit information about a sensor, e.g. measurement parameters etc.

The following abstract highlights the differences between SOS and the SensorThings API. The interested reader can find a full comparison in (Jazayeri, Liang, & Huang, 2015). In contrast to the *Representational State Transfer Principle* (REST), which is used by the SensorThings API, the SOAP interface used by SOS is in general more complex to use and has a bigger entry hurdle (zur Muehlen, Nickerson, & Swenson, 2005). The SensorThings API instead, using the *JavaScript Object Notation* (JSON), is more efficient regarding the amount of transmitted data, than the XML-encoded data transfer of the SOS (Mumbaikar & Padiya, 2013). However, SOS can have a JSON encoding extension, just as a SensorThings Service could have an XML encoding extension. As the SensorThings API has been developed by the OGC, it is backwards compatible to the SOS on a service level: all service functions defined by the SOS can be found in the SensorThings API. In contrast, through the implementation of ODATA filters, the SensorThings API offers more query capabilities on the service level, which cannot be answered by an SOS.

SENSORTHINGS API

To ease out the integration of different devices in data driven applications, the OGC developed a flexible, easy to use standard for the exchange of information in the context of the Internet of Things. With the SensorThings API standard, a framework, which interconnects sensing devices, data and applications over the web, is provided. The standard focuses on time-series data. Time-series are measurements of the same observed property, for instance the temperature, taken at different points in time. They can be measured in a more-or-less regular interval, e.g. every hour. The sensor can have either a fixed (fixed-point) or a moving (moving-point) location. An example for a fixed-point time-series are automatic water level gauges or more general the national weather stations available throughout Europe. These sensors are located in-situ and generate data at a fixed time interval. Sensors that can be hand-held or mounted on a vehicle or drone, and therefore have a different location for each measurement generate moving-point time-series. Drone-collected meteorological values are an example of this type.

DATA MODEL

The OGC SensorThings API data model not only covers plain sensor measurements, but also metadata like the unit of the measurement, a sensor description or a location. The metadata is connected to the original data stream.

The data elements are linked to each other enabling the user to find all necessary information of interest. The data model consists of eight entities, including properties and relations, which are shown in Figure 1. The model is described in following.

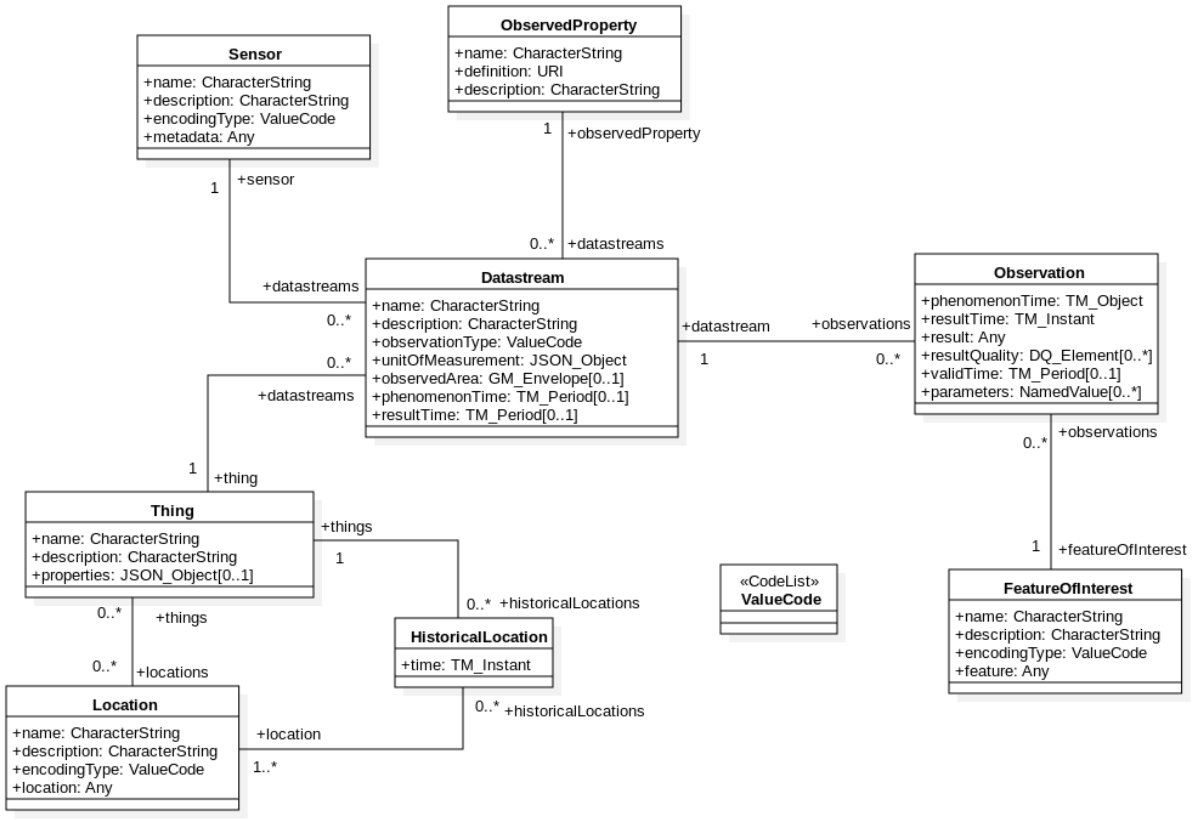


Figure 1: SensorThings API data model (Open Geospatial Consortium, 2016)

A *Thing* is a virtual or physical object. Depending on the use-case, the *Thing* can be the object being observed, like a river section, or the sensor platform, such as a satellite. *Location* describes the position of a *Thing*. A position can be described through geographic locations, encoded as points or areas. Symbolic locations, like a postal address, are possible, too. The *HistoricalLocation* is the link between a *Thing* and a *Location*, with the time indicating when the *Thing* was in a certain *Location*. A moving *Sensor* has several *HistoricalLocations*. A motionless *Thing* has none. This is defined through the SensorThings API, where the *HistoricalLocation* is created, when the *Thing* moves for the first time. A *Sensor* generates the data, which is described through the OGC SensorThings API Data Model. A *Sensor* can collect multiple *Datastreams*. A weather station for example can collect both temperature and humidity; in this example, the *Sensor* weather station would have two entities *Datastream*, one for each temperature and humidity. *Observation* contains the measurement made by a *Sensor*. An *ObservedProperty* is a characteristic of the *FeatureOfInterest* that is observed by a *Sensor*. For example, the water level in a river, or its temperature. A *Datastream* unites *Observations* of an *ObservedProperty*, which were made by a *Sensor* and are linked to a *Thing*. The *FeatureOfInterest* can be the geographic area or location for which an *Observation* was made. This can be the same as the *Location* of the *Thing*, which is often the case for in-situ sensing. In the case of remote sensing, the *FeatureOfInterest* can be different from the location of the *Thing*, dependent on what is chosen as *Thing*. The *FeatureOfInterest* is a geographical point or a polygon encompassing an area or volume, usually encoded in the format GeoJSON.

The relations between all these entities are described through the data model; this ensures finding all data entities that belong to another and only make sense in their own context.

REST

The OGC SensorThings API offers a RESTful interface for accessing the stored data. The REST programming paradigm is a well-known approach for realizing distributed systems. It is based on top of the Hypertext Transfer Protocol (HTTP), which forms the basis of the World Wide Web. REST is used for inter-machine communication and is widespread around web services. Alternatives are for example SOAP or Remote Procedure Calls.

The idea of REST was developed by Roy Thomas Fielding, published in his dissertation in (Fielding, 2000).

Fielding presents principles, which every REST-service must follow without suggesting how to implement them. The principles are described in the following. The first principle is the Client-Server Architecture, known from the World-Wide-Web. A server offers a service, which can be requested by a client. Through the usage of the widespread HTTP-protocol, a REST client implementation is available for nearly every programming language. The second characteristic of a RESTful service is its statelessness: every message sent to a REST service must contain all information needed to process this request. This brings two benefits: firstly, the service can be scaled according to the required usage. Secondly, it decreases complexity, since all information is summarized and no application state needs to be shared between two requests.

Other than its alternatives, REST demands unified interfaces. This contains for example the addressing scheme. Every entity in REST has to be uniquely identifiable, which usually is implemented through Uniform Resource Locators (URLs). The representation of entities is often achieved through JSON. Requests to the server are transmitted via HTTP. Thus, the HTTP-methods GET, POST, PUT, PATCH and DELETE are used to interact with the server. Hereby, GET is used to request information. To create a new instance of an entity the POST operation is used. By sending PUT (overriding a whole entity) or PATCH (overriding only provided attributes) messages, existing entities can be modified. DELETE is finally used to remove entities. For the SensorThings API, this means when entering the main URL of a SensorThings API server in a web browser, a GET request is issued to the server. The response of the server will contain a JSON file as shown in Figure 2.


```
value:
  0:
    name:   "Datastreams"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/Datastreams"
  1:
    name:   "MultiDatastreams"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/MultiDatastreams"
  2:
    name:   "FeaturesOfInterest"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/FeaturesOfInterest"
  3:
    name:   "HistoricalLocations"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/HistoricalLocations"
  4:
    name:   "Locations"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/Locations"
  5:
    name:   "Observations"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/Observations"
  6:
    name:   "ObservedProperties"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/ObservedProperties"
  7:
    name:   "Sensors"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/Sensors"
  8:
    name:   "Things"
    url:    "https://beaware.server.de/SensorThingsService/v1.0/Things"
```


Figure 2: FROST start page

As shown in Figure 2, the response contains all data model entities, as well as their URLs. Through these URLs, each individual on the server is addressable (e.g. */Sensors(10)*). Analogous to fetching data, an instance can be created, modified or deleted by sending a POST, PUT, PATCH or DELETE command to the appropriate URL. Since the database can contain a large amount of data, only a subset of all available data is returned for a GET command. This prevents both the server, as well as the client from an overload. Further data is sent upon request.

ODATA

The previous section showed how data can be retrieved and modified by using the REST interface. For many applications, it is not sufficient to retrieve all available data. Conditional upon the large variety of stored data, powerful and expressive filter mechanisms are required to receive the data of interest. In the SensorThings API, these are realized by applying the Open Data Protocol (OData), which is standardized by the Organization for the Advancement of Structured Information Standards (OASIS). It allows projections and filters similar to the Structured Query Language (SQL), which are specified as query strings in the URL. Projections can be done by naming the queried attributes in the *$select* parameter. For example, */Things?$select=@iot.id,description* will only select the id and the description of *Things*.

By passing the *$filter* parameter, it is possible to query for specific results. For example, */Observations?$filter=result gt 5* will return all observations that have a result value greater than 5. A wide range of filtering operators are supported; an exemplary list of supported functions is shown in Table 1.

Table 1. Exemplary list of functions that can be used with OData in the URL of requests

Comparison	Mathematical	Logical	String Functions	Geospatial	Date and Time
gt (greater than)	add (addition)	and	substringof(p0,p1)	geo.intersects(g1,g2)	now()
ge (greater equal)	sub (subtraction)	or	indexof(p0,p1)	geo.distance(g1,g2)	mindatetime()
eq (equal)	mul (multiplication)	not	trim(p0)	st_equals(g1,g2)	maxdatetime()
le (less equal)	div (division)		concat(p0,p1)	st_within(g1,g2)	date(t1)
lt (less than)	mod (modulo)			st_overlaps(g1,g2)	time(t1)
ne (not equal)					

MQTT

Message Queuing Telemetry Transport (MQTT) is an open-source protocol standardized by OASIS (Hunkeler, Truong, & Stanford-Clark, 2008). It follows the publisher-subscriber pattern. Thus, it is predestinated for collecting the data of IoT-sensors. By using this pattern, subscribers can register to a topic, which broadcasts information they are interested in. The information is initially provided by a publisher that sends a message to the corresponding topic, as soon as it gets available. A message broker (included in a SensorThings API compliant server) takes care of the subscriptions and forwards the messages to all the subscribers registered to the topic. A topic is a string that can have several hierarchical levels, separated by a slash. Through this, a client receives only the information published within these topics. The naming of the topics is analogue to the URLs of the entities in the SensorThings API implementation (e.g. */Datastreams*; see Figure 2 for others).

An implementation of the SensorThings API offers, next to the RESTful HTTP interface, an additional MQTT interface. The publisher-subscriber pattern is realized twice. On the one side, a SensorThings Server subscribes to the topics, which represent the entities. Sensors can use this interface to publish new observations, which are created on the server. On the other side, a sensor or - more often - a subsequent processing component may subscribe to changes of instances: this allows the implementation of features that need to directly react on changes (for example, by subscribing to the measurements of a water level sensor, a procedure can be triggered as soon as a threshold is reached).

Figure 3 shows a simplified schematic example: The thermocouple on the top right side posts its observations of 6.03°C to topic *v1.0/Datastreams(5)/Observations.* The actuator on the lower right side subscribes to the same topic and uses it as input for further processing: in this case, the gears would turn by 22.4° and could, for example, open or close a window. Clients can subscribe to topics (like the previously shown example) or to specific instances matching a filter (see previous chapter).

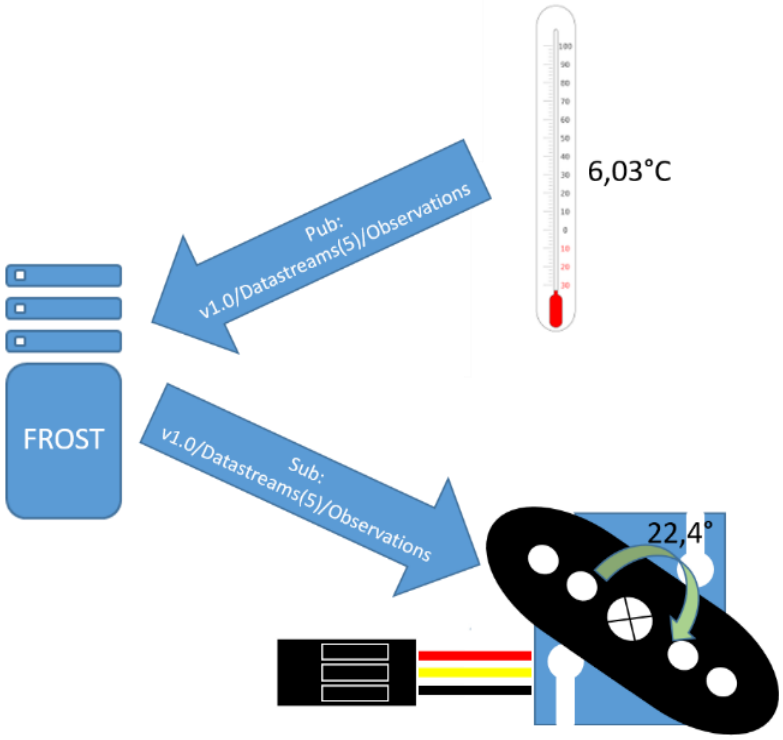


Figure 3: Using the MQTT Broker of FROST to interconnect multiple components

FROST

FROST is an open-source implementation of the SensorThings API standard, developed by Fraunhofer IOSB. The application was designed according to the SensorThings API standard and implements the named data model, REST-interface and MQTT extension and the specified ODATA querying mechanism. Therefore, the application is certified OGC compliant (Open Geospatial Consortium, 2016). The source code is publicly available on *https://github.com/FraunhoferIOSB/FROST-Server* under GNU Lesser General Public License v3.0. It is written in the Java programming language. Internally, FROST uses a PostgreSQL database for data storage, with the PostGIS extension to support geospatial queries. PostgreSQL is an object-relational database and PostGIS extends the database for spatial information. (For further information about both, please visit: *https://www.postgresql.org/* and *https://postgis.net/*).

To start an instance of FROST, different deployment possibilities exist. For example, the server is available as a pre-build WAR-file, which can be run on a web-server like Apache Tomcat or Wildfly. Both are freely available open source HTTP servers. The webpages *http://tomcat.apache.org/* and *http://wildfly.org/* will give the interested reader access to deeper information. Furthermore, FROST is available as a Docker image. This allows an easy start of an instance without the need of further dependencies, for testing and production-ready usage within a virtual environment. On *https://www.docker.com/* the software Docker is introduced. To scale out the deployment, a Helm (https://helm.sh/) chart for Kubernetes is available. Kubernetes (*https://kubernetes.io/*) is an open-source container orchestration platform, initially developed by Google, which offers the possibility to run the application in bigger cloud environments.

ARCHITECTURE

In this section, we will shortly describe the architecture of FROST. Especially when scaling the server in a cloud environment it is important to understand the four different FROST components. The different modules and their interaction are visualized in Figure 4.

The first component is the HTTP-frontend; it handles all incoming requests from the REST interface. In Figure 4 an example is shown, where this component is scaled to the number of two. Changes are directly written into the Database (second component) to have them persistent. Additionally a message is sent through an internal Message Bus (third component) to inform the MQTT components about the changed content. This fourth component evaluates if there are MQTT-subscriptions to which this information needs to be forwarded and does so if needed. In the example in Figure 4, this component is scaled to the amount of two.

There are two possibilities how the different components are bundled together. Using the WAR artifact or the "All-in-One"-Docker image, all components, except for the PostgreSQL-database are running inside a single instance of a Java Virtual Machine (JVM) as monolithic application. With an increasing number of requests, there might be the need to scale FROST. Since this horizontal scaling is not possible within a single JVM instance, there is the possibility to run all components separately. Even if there is only one instance of the database and the message bus needed, the MQTT and HTTP components can be scaled independently. Since all state is handled inside the database, those two components are stateless.

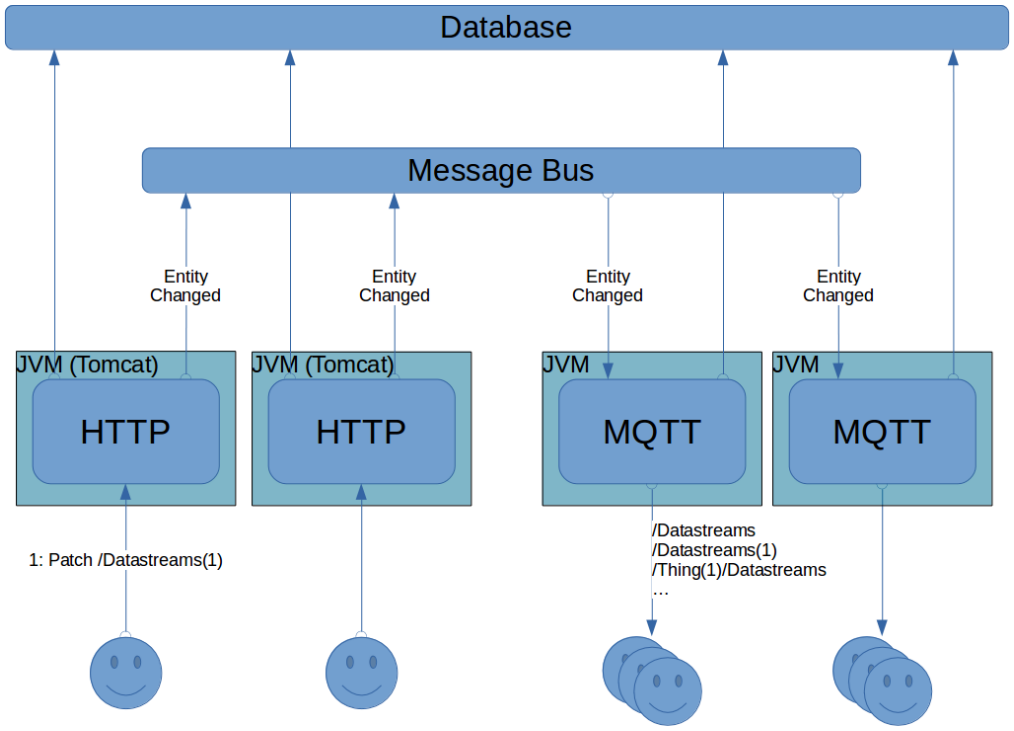


Figure 4: The FROST architecture

COMPATIBLE SOFTWARE TOOLS

Although the SensorThings API is comparatively new, the number of software tools around it is growing. In the following, we present a short list of freely available open-source software, which is compatible with FROST.

CHILLImport

The software is meant for application cases, where collected data is stored in a rudimentary file format and cannot be uploaded by an automated task. This for example is the case, for every sensor placed in a region without internet connection.

CHILLImport is a web-application whose main task is to offer a graphical interface to import data, whereas the software is flexible regarding the input file format and structure. The software converts the measured data into the SensorThings API data model and subsequently imports it into a FROST instance. To adapt different file formats and structures, the software can store and retrieve the configurations for the input file. The configurations can be reused, in case measured data with the same structure needs to be imported again. Configurations can be created by IT-affine users, whereas it is quite complex for an unexperienced user. During the import, an automatic duplicate check between the data to be imported and data stored within the server is conducted. This prevents redundant data within FROST. If an import fails, due to a corrupt import file, loss of connection or similar, CHILLImport prints out a file, in which the user can find all the data that was not imported.

The software is freely available under MIT license and can be found at GitHub:
https://github.com/Chillimport/ChillImport.

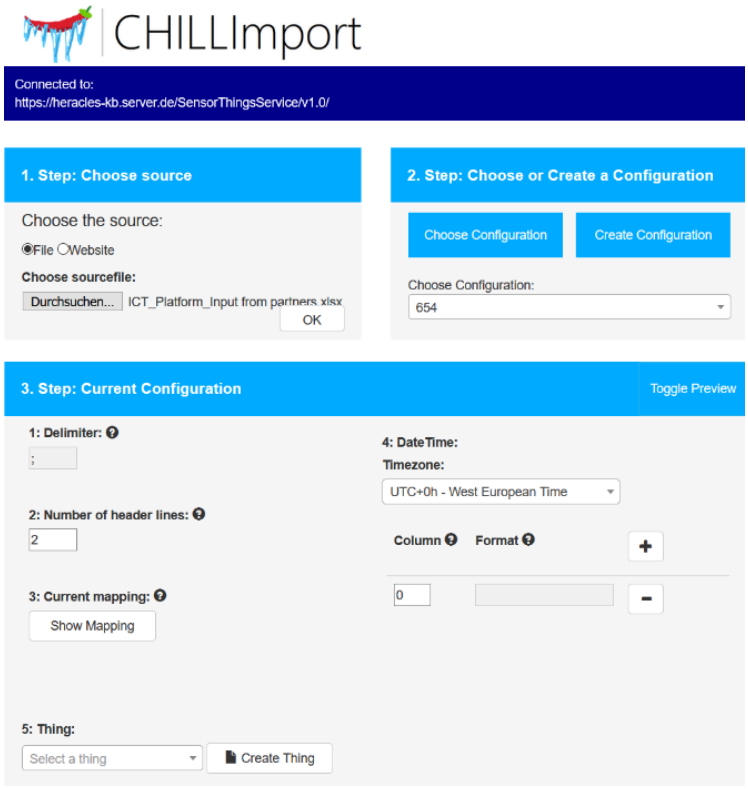


Figure 5: The CHILLImport user interface

FROST-Client

The FROST-Client is a Java library facilitating the interaction with servers and aims to simplify the development of SensorThings enabled client applications. It provides the possibility to connect to a server, which implements the SensorThings API, identified through a URL and create, read, update or delete data. These operations are available through Java classes and methods and therefore allow the easy integration of sensor data into an application.

It is freely provided under MIT license and can be found here: *https://github.com/FraunhoferIOSB/FROST-Client*.

The code snippet in Figure 6 shows a code snippet in the Java programming language, to connect to a FROST instance, posting a new *Thing*, updating it and finally deleting it by using the FROST-Client library.

```
URL serviceEndpoint = new URL("http://example.org/v1.0/");
FROSTService service = new FROSTService(serviceEndpoint);

Thing thing = ThingBuilder.builder()
    .name("Thingything")
    .description("I'm a thing!")
    .build();
service.create(thing);

// get Thing with numeric id 1234
thing = service.things().find(1234l);
// get Thing with String id ab12cd
thing = service.things().find("ab12cd");

thing.setDescription("Things change...");
service.update(thing);

service.delete(thing);
```

Figure 6: The FROST-Client

FROST-Manager

The FROST-Manager expands the FROST-Client through a graphical user interface managing data on any SensorThings Server. After configuring the URL of a FROST instance, it offers simple means for creating, retrieving, updating or deleting entities.

FROST-Dashboard

The FROST-Dashboard is one possibility to visualize data from the FROST-Server. It can display graphs showing sensor data over time or a visualization of alert levels in traffic lights, as shown in Figure 7. Further, it offers bar graphs, gauges or thermometers from which the user can configure the appropriate visualization.

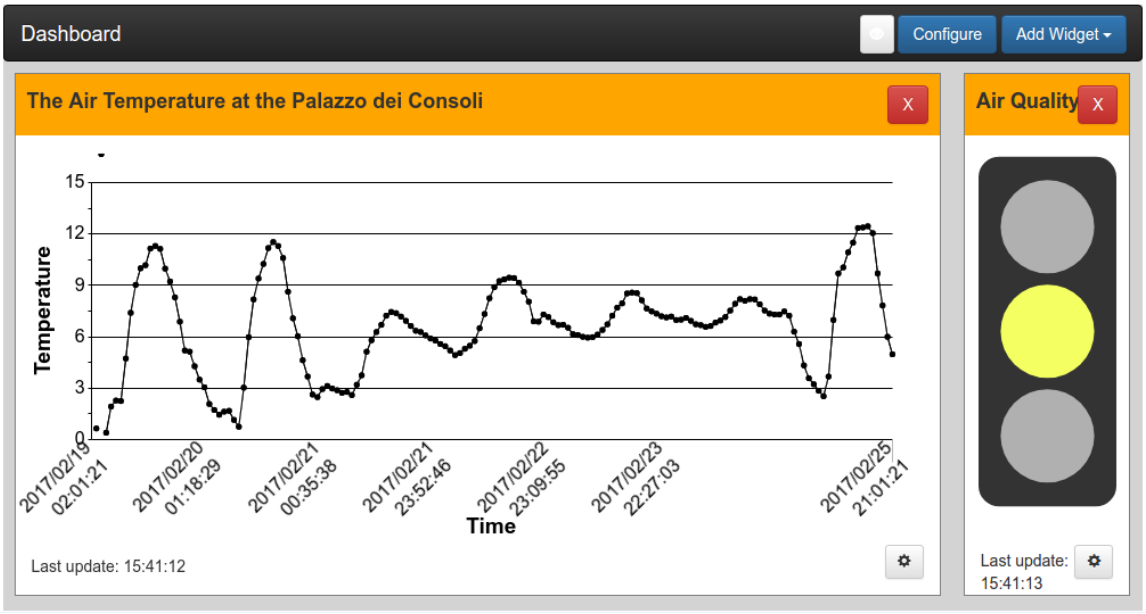


Figure 7: The FROST-Dashboard

Grafana-Dashboard Plugin

Grafana is a well-known application for displaying various kinds of time-series data. Especially for displaying metrics (e.g. of computer hardware or an application) it is very popular. It is also usable for displaying sensor data. A plugin is available to integrate data from a SensorThings API server, which can be found at the Grafana webpage: *https://grafana.com/plugins/linksmart-sensorthings-datasource.*

APPLICATION

This section presents two EU-funded projects, namely beAWARE and HERACLES, in which FROST is integrated as a central component within a bigger Decision Support System (DSS). By presenting both projects, we demonstrate the utilization of the SensorThings API in a practical way and prove the applicability in a hands-on context.

BEAWARE

The main goal of beAWARE is to develop a novel framework for crisis management that manages and supports authorities and end users before and during crises caused by extreme weather events. Up to now, the emergency management landscape consists of many splintered solutions for different problems. This leaves emergency management agencies with the task to integrate the best solutions for them into their system and to make sure that they properly work together. However, this represents a huge effort that many agencies are not able to make. The holistic approach to realize a crisis management framework provided by beAWARE shall help in this regard. The integrated solution of the DSS will include forecasts, early warnings, transmission and routing of the emergency data, aggregated analysis of multimodal input and management of the coordination between the first responders and the authorities.

FROST IN THE CONTEXT OF BEAWARE

Sensor data plays an important role in generating early warnings and gaining situational awareness. This could be for example meteorological data (temperature, humidity and rainfall), or the water level of a river section as well as weather forecasts. Depending on the use case, different sorts of sensors are available and their data can vary strongly regarding their type, frequency and format which makes the integration into a single platform difficult. FROST helps to solve this problem since it provides a unified interface for the sensor data. Further, it takes care of the sensor data management and offers rich querying mechanism, based on, for example, location of the feature of interest, time, type of sensor, and/or observed property.

When applying the SensorThings API model to beAWARE, for example to a water level gauge in a river section, the *Thing* could be the river section of which a *Sensor* measures the water level. The *Thing* would have a *Location*, with a polygon describing the layout of the river section. Since river sections usually do not move much, there would be no *HistoricalLocation*. The *Sensor* entity would describe the exact properties of the water level gauge, like brand, type and accuracy. *ObservedProperty* would be named "water level" and contains an exact reference to a water level definition. For this set of *Thing*, *Sensor* and *ObservedProperty*, there would be a *Datastream* that groups the water level observations of the sensor. Each value measured by the *Sensor* would be stored as an *Observation*. Since the *Sensor* is static, each *Observation* is linked to the same *FeatureOfInterest*, which has the exact coordinates of the *Sensor*. For a temperature sensor located at the same spot as the water level gauge, the same *Thing*, *Location* and *FeatureOfInterest* entities would be applied. Only the new entities *Sensor*, *ObservedProperty* and *Datastream* would have to be added.

In Figure 8, the locations of all sensors around Vicenza, a city in the north east of Italy, that are available in the server are displayed on a map.

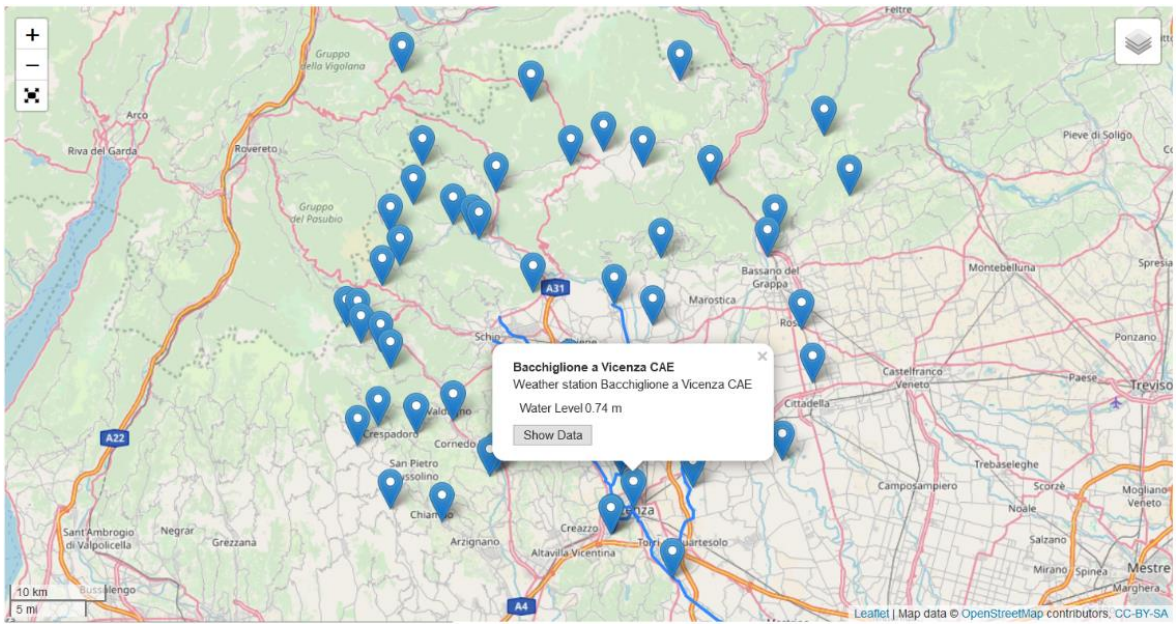


Figure 8: Map with water level and weather station sensors

By clicking on a sensor in the map, the data of the sensor, which is stored in FROST, will be visualized in a graph (see Figure 9). By selecting several sensors or by choosing several *ObservedProperties* more than one graph can be displayed in the diagram, which allows for a direct comparison of the data.

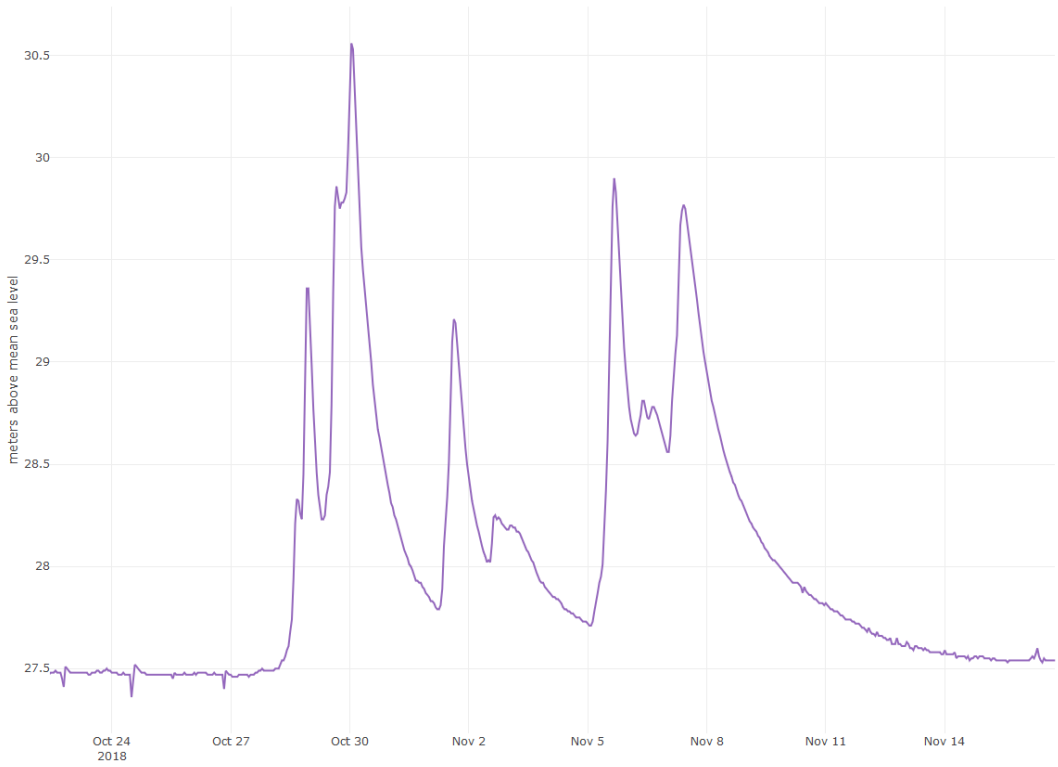


Figure 9: A graphical visualization of water-level values

HERACLES

The main objective of the HERACLES project is to design, validate and promote responsive systems and solutions for effective resilience of Cultural Heritage (CH) against climate change effects, considering as a mandatory premise a holistic, multidisciplinary approach through the involvement of different expertise (industry, scientists, conservators, social experts, decision, and policy makers). This is pursued through the development of a system exploiting an ICT platform able to collect and integrate multisource information in order to provide complete and updated situational awareness and support decision making for innovative measurements improving CH resilience, including new solutions for maintenance and conservation. The HERACLES effectiveness is validated in two test beds, namely Heraklion in Crete with the Knossos palace and the Sea Fortress and Gubbio in Italy with Palazzo dei Consoli and the medieval town walls. These test beds represent key study cases for the climate change impact on European CH assets.

FROST IN THE CONTEXT OF HERACLES

All time-series data collected in the HERACLES Project is stored in a FROST instance. Live data coming from sensors installed by the project-partners in the test-bed locations are automatically imported into the server. As in beAWARE, the sampling frequency of the sensors can differ a lot, for example, one data point per minute from a weather station to several 100 data points per second for an accelerometer. Therefore, automatic aggregations are applied for each sensor, in hourly and daily intervals. A visualization component in the HERACLES user interface will automatically choose the aggregation level that fits best to the time interval the user wants to see.

The following picture shows a crack on a building (Crack *C1*) that is monitored in the context of the HERACLES project. A thermocouple *T1* measures the surrounding temperature, while the linear variable differential transformer *LVDT1* measures the width of a crack (see Figure 10). The exceeding of threshold values or the predicted exceeding of a threshold alerts the cultural heritage manager, who triggers appropriate conservation or mitigation actions.

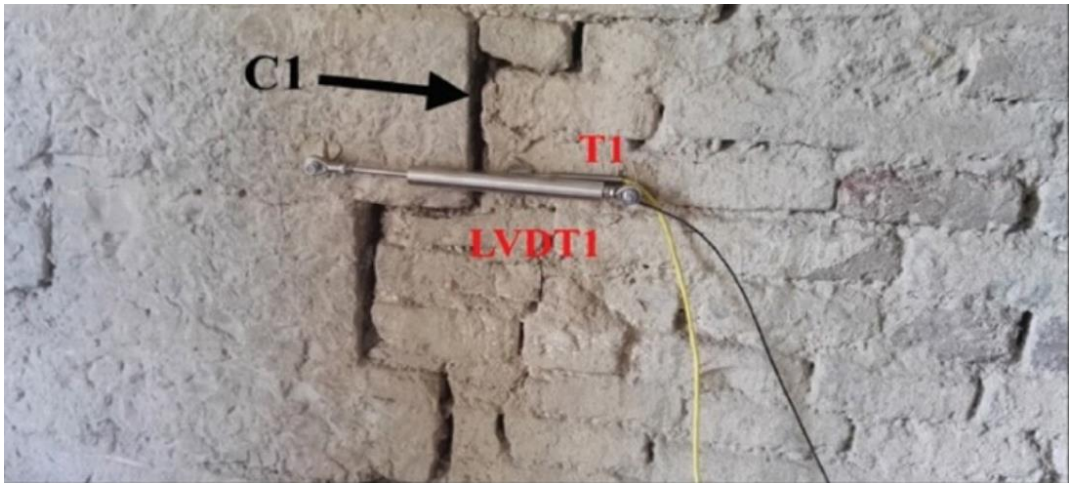


Figure 10: The observation of a crack by measuring temperature and crack width

The changing environmental parameters are collected through the sensors and posted once per day through an HTTP-POST request to the FROST instance deployed within the HERACLES cloud environment. The project partners can access both the raw data stored on the server for further analysis, or access a graphic visualization generated within the HERACLES user interface.

FUTURE DEVELOPMENT

The SensorThings API standard is comparatively new but the number of products implementing the standard is growing quickly. In parallel, the OGC continues developing the SensorThings API standard. Until now, by using the term SensorThings API, we referred to the first part of multiple specifications. We only considered the management of sensors, their metadata and measurements. Still, in the context of IoT more and more devices appear that not only monitor the environment but also manipulate the real world, by executing tasks. The OGC specification "OGC SensorThings API Part II - Tasking Core", released for public comment on February 20, 2018, adds actuation to the SensorThings API (Open Geospatial Consortium, 2018). In terms of the SensorThings API Part II - Tasking Core standard, such a device is called an *Actuator*. This can be any entity that accepts a defined parameter and uses it for further processing. Thus, an *Actuator* is not limited to hardware devices; an actuator can be anything that accepts a task to be executed, including, but not limited to, mathematical models (e.g. calculating min/max or the average of measurements during a time interval). The generic approach is analogue to the presented SensorThings API. The genericity allows the integration of many different devices as *Actuators* and it is possible to describe all necessary parameters to control actuators, and to define tasks that an actuator can execute.

The Tasking Core adds three entities to the SensorThings API: *Actuator*, *TaskingCapability* and *Task*:

- **Actuator:** A hardware or software component that can execute tasks.
- **TaskingCapability:** Describes the parameters that can be supplied to a task.
- **Task:** A task to be executed, with values for the parameters described in the linked *TaskingCapability*.

In the context of Crisis Management, Part II of the SensorThings API promises a lot of potential that needs to be investigated. Since every crisis needs a specific and tailored-to-its-needs response, the used equipment differs from crisis to crisis. In the context of IoT, new tools for first responders emerge such as remote controlled or autonomous robots. Rigos et al., for example, discuss the usage of a remote controlled robot that can crawl into collapsed buildings. The usage of state-of-the-art tools during a crisis is desirable, but imposes challenges: as we already motivated in the introduction, just like sensors, actuators require a standardized data model. This allows making efficient use of many actuators and unfolds synergy effects through their coordinated operation. These synergy effects can be exploited, when a single point for command and control exists, where the management of every controllable piece of equipment is possible. Another use-case is the automated response upon certain events: if a sensor posts an observation to a FROST instance, that exceeds a specific limitation, a standardized operation procedure can be executed upon this. Set the case, a water level sensor observes a value over a certain threshold; the automatic routine could imply the opening of a floodgate within the river area, to reduce the water pressure against its riverbed. The FROST development to support Part II of the specification is already ongoing. A generic data model for actuators could act as base for this single command and control point.

EXERCISES AND INSTRUCTIONS

The live demo will be split in two sections focusing on both technical users and end-users.

Firstly, the installation of a FROST instance will be demonstrated with the help of a Docker image. The link to the required image can be found under *https://github.com/FraunhoferIOSB/FROST-Server*. Secondly, sensors will be inserted into the data model. Thirdly, a short script in the will post data via HTTP to FROST. Instead of using live sensor data, a random generator will provide data values. An example query to retrieve data will be executed.

After that, more sophisticated use-cases from the beAWARE project will be presented, like accessing live data weather data or analysis results. Access to sensors will be provided through maps; with the help of graphs and forecasts, end-users can intuitively assess the situation and give a suggestion, if preparedness actions should be started for a city.

CONCLUSION

In this paper, we have motivated the use of an open standard to manage time-series data in emergencies to enhance situational awareness and to organize an efficient response. We argue that time-series data bears huge potential but also challenges. Though the challenges imminent in IoT-data are complex, they can be overcome by rigorously adopting standards and implementing a uniform interfacing concept. In this context, the standard SensorThings API has proven itself beneficial, since it provides an open, geospatial-enabled and unified way to interconnect sensors, data and applications of the Web. The FROST implementation is a lightweight and open-source implementation of this standard and can be utilized to collect and disseminate time-series data in an emergency. The exploitation of the data improves situational awareness in different settings, including natural disasters. The applicability of FROST has been demonstrated in the projects beAWARE and HERACLES. Furthermore, through the open-source approach of FROST, a vibrant ecosystem has already formed and supplementary software is publicly available.

ACKNOWLEDGMENTS

Funding: The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under Grant No. 700395 and Grant No. 700475.

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

Fielding, R. T. (2000). *Architectural Styles and the Design of Network-based Software Architectures.* Dissertation, University of California. Irvine, CA.

Hunkeler, U., Truong, H. L., & Stanford-Clark, A. (2008, January 06-10). MQTT-S - A publish/subscribe protocol for Wireless Sensor Networks. *2008 3rd International Conference on Communication Systems Software and Middleware and Workshops*.

Jazayeri, M. A., Liang, S. H., & Huang, C.-Y. (2015, September 22). Implementation and Evaluation of Four Interoperable Open Standards for the Internet of Things. *Sensors, 15 (9)*, pp. 24343-24373.

Lee, I., & Lee, K. (July-August 2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. In *Business Horizons, Volume 58, Issue* (pp. 431-440). Indiana: Elsevier.

Leonard, A., Mitchell, T., Masson, M., Moss, J., & Ufford, M. (2014). OData Source. In *SQL Server Integration Service Design Patterns, Second Edition* (pp. 251-260). Berkely, CA: Springer.

Li, T., Liu, Y., Tian, Y., Shen, S., & Mao, W. (2012, November 20-23). A Storage Solution for Massive IoT Data Based on NoSQL. *2012 IEEE International Conference on Green Computing and Communications*, pp. 50-57.

Mumbaikar, S., & Padiya, P. (2013, May). Web Services Based on SOAP and REST Principles. *International Journal of Scientific and Research Publications, Vol. 3 Issue 5*, pp. 1-4.

Open Geospatial Consortium. (2012, 04 20). *opengeospatial.org.* Retrieved November 30, 2018, from https://portal.opengeospatial.org/files/?artifact_id=47599

Open Geospatial Consortium. (2016, July 26). *OGC SensorThings API Part 1: Sensing*. Retrieved November 30, 2018, from http://docs.opengeospatial.org/is/15-078r6/15-078r6.html

Open Geospatial Consortium. (2016, Januar 11). *opengeospatial.org*. Retrieved November 30, 2018, from http://www.opengeospatial.org/resource/products/details/?pid=1371

Open Geospatial Consortium. (2018, August 01). *opengeospatial.org*. Retrieved November 30, 2018, from http://www.opengeospatial.org/standards/requests/162

Rigos, A., Sofianos, D., Sourlas, V., Sdongos, E., Koutsokeras, M., & Amditis, A. (2018). A resilient, multi-access communication solution for USaR operations: the INACHUS approach. *14th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, (pp. 255-261). Limassol: IEEE.

Statista.com. (2019). (Statista) Retrieved November 30, 2018, from https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/

zur Muehlen, M., Nickerson, J. V., & Swenson, K. D. (2005, July). Developing web services choreography standards—the case of REST vs. SOAP. *Decision Support Systems Vol. 40, Issue 1*, pp. 9-29.

Robust Private Web Maps with Open Tools and Open Data

Bas Lijnse
Netherlands Defence Academy
b.lijnse@mindef.nl
Radboud University Nijmegen
b.lijnse@cs.ru.nl

ABSTRACT

Crisis management information often has a geospatial dimension that allows it to be visualized on a map. As more and more systems are developed as web-based applications, maps have also become a common sight in such applications. The de-facto solution to add maps to web-based applications is to integrate a third-party service. For web-based crisis management information systems, this approach has two disadvantages. First, the third-party service must be available and reachable. Second, by using third-party services you implicitly share what you are viewing, with the risk of unintentionally exposing sensitive location information. In this *Tool Talks* paper, we show how to create a robust and private alternative for web-based maps using open source tools and open data.

Keywords

Web Maps, Web-Based Systems, Tools, Open Data, OpenStreetMap

INTRODUCTION

Many crisis coordination systems, such as incident response or command and control systems, deal with geospatial information. The stereotype image of a command centre typically features a map projected on a large screen. When designing such crisis management information systems, one of the important design decisions is to choose what tools to use for this geographic visualization.

A general long-time trend in the development of information systems is to move towards web-based systems. Modern web-browsers, protocols and standards are powerful enough to build every conceivable application. Even complex desktop applications such as office suites are now available as web-based versions. With more software development moving to web-development, it is safe to assume that a significant share of future crisis management systems will also be developed as web-based systems.

Integrating maps into web-based information systems is trivial. Search giants such as Google and Microsoft's Bing provide free application programming interfaces (API's) that let you integrate their maps easily. Additionally there are dedicated commercial providers such as Esri or Mapbox that have similar offerings but also offer more options, services and customizations. A well-known open-source alternative is OpenStreetMap (OpenStreetMap Contributors 2018b) that can be integrated just as easily.

Integrating these online third-party API's is a quick and easy solution for integrating a map into a web-based information system. It also has the added benefit of not having to manage your own map data. However, they also have some inherent properties that may be problematic for crisis management applications. The first and obvious property is that they create a dependency on an online third-party provider. Without an internet connection the maps do not work. This is not an issue for public online systems, which are not available in that case anyway. But for crisis management systems, that despite being web-based may run on a local network without a reliable connection to the internet, this can be a serious liability.

Another property that may be less obvious, is that using a third-party map provider is a potential privacy concern. Web-maps are typically not loaded all at once, but incrementally. By retrieving specific parts of a map, you implicitly share with the map-provider which geographic region you are looking at. Depending on the level of

network security, this information could be seen by additional third parties. How sensitive this information is depends on the specific context, but in crisis management applications one cannot simply assume that it is not sensitive at all. For example the OCHA policy paper "Humanitarianism in the Cyberwarfare Age" (Gilman and Baker 2014) states:

> Information about places and objects, such as pre-positioned stocks or medical facilities, is critical to a humanitarian response, and may be very sensitive.

Although this paper considers protection of personal information to be a more important concern, it still acknowledges the potential sensitivity of location information.

An alternative to using third-party map providers in your web applications is to serve your own map content. This approach enables several options to improve robustness. You can provide a map service inside a local area network, making it independent of internet connectivity. Moreovere, for situations where local network infrastrucure cannot be relied upon, it enables the possibility to bundle maps for offline use. When you use your own map service, accidental sharing of sensitive locations with a third-party is also not an issue, because no third-parties are involved.

Creating, and serving your own web maps is not as easy as integrating a Google Maps widget, but is not as difficult as you might expect. With many open sources of geographic information publicly available and a wealth of open-source tools for storing this information and rendering maps, this is a viable alternative to third-party map providers. You need a basic understanding of geographic information, but you do not need to be an expert in geographic information systems (GIS) expert to setup and use these tools.

For this *Tool Talks* paper we consider the situation in which you are only interested in a relatively small geographic area and do not need frequently updated maps. In this case the simplest tool-chain suffices: you prepare the maps once using a batch process, and integrate them in an application using a Javascript library and any basic web server.

The first time we applied this tool-chain was for the Incidone system (Lijnse et al. 2012). This was a prototype incident coordination system based on the operations of the Netherlands Coast Guard. This system was designed to be able to operate in a closed network without reliable internet connectivity. Online map services were therefore not an option.

Since this first prototype the tools that were used to create the such maps have evolved, but the basic process has stayed the same. In this paper we aim to explain the tool-chain and how to use it to create your own private maps. We aim for a high enough level of abstraction that it will stay applicable even as details of the specific tools continue to evolve. Additionally we provide a practical section that helps you set up the tool chain with the latest software versions (at the time of writing), and helps you understand the roles of various components.

We consider the main contributions of this paper to be:

- An explanation of the necessary tools and process to create your own private web-maps from open data.
- A practical guide to get started, with exercises to further understanding of the tool chain
- A convenient script that automates the process for a concrete example

Because this paper is a *Tool Talks* paper, it is organized as a practical guide: We start with an explanation of the necessary preliminary concepts of GIS and web-based maps in "Preliminary Concepts". This is followed by a detailed explanation of th tool chain in "The Tool-chain". We conclude with the practical exercises in "Exercises" and final remarks in "Conclusion".

PRELIMINARY CONCEPTS

To set up and use the tool chain we describe in this paper, you do not need to be a GIS expert. However, you need to have a basic understanding of how maps, and in particular web-based maps, are constructed. In this section we cover those basic concepts.

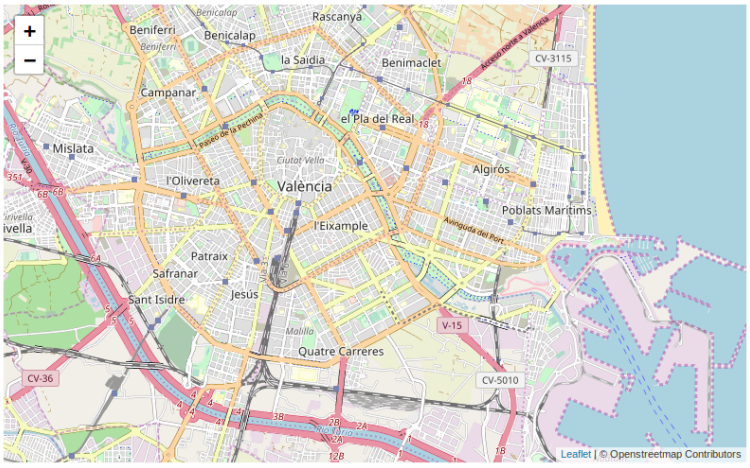


Figure 1. Example of web-based "Slippy map"

Map Basics: Layers, Points, Lines and Polygons

Essentially, a map is nothing more than the projection of *things* that have a location onto a flat two-dimensional surface. The basic data model that underlies any map is therefore fairly simple. The simplest thing you can put on a map is some point in space. Using points you can show the locations of objects. This representation is by definition an approximation, because a point is infinetely small and any object, even small ones take up some space. The next entity we can represent on a map is sequence of points, a line. Lines can be used to represent things like roads or waterways. Another interpretation of a sequence of points is a polygon. In a polygon the points define the outline of something. This can be used to represent areas: For example plots of land, or the outlines of buildings. Points, lines and polygons are the basic types of things you can put on a map. The final concept we need is a way to compose all these features. This is done using the concept of a layer. A layer is simply a collection of lines, points or polygons. A map is then defined as a stack of layers. Because the mapped objects are projected on a two-dimensional plane, a layer adds a third dimension. Layers define the order in which a map is drawn. Typically from bottom to top. This grouping makes it possible to specify that a set of lines that represent roads is drawn on top a set of polygons that define the underlying land areas. In interactive GIS applications the concept of layers also makes it easy to interactively show or hide collections of related features.

Storing Geographic Information

Because the data model is very simple you need little to store a geographic dataset. A small collection of points could easily be stored in a basic spreadsheet with three or four columns. One to hold a (unique) identifier and at least two more to represent the coordinates of the points. Depending on the type of data the coordinates can have two or three dimensions. The elevation of points is not always considered. Sometimes elevation has no meaning for that type of data, but for certain computations, such as determining an accurate distance between two points, the third dimension is necessary. One thing to note here is that there is more than one way to represent coordinates. There are different coordinate systems and to interpret a location correctly you need to know the coordinate system that was used. Luckily these coordinate reference systems are well standardized and documented, but you need to be careful to interpret the coordinates in the correct reference system.

A simple spreadsheet is enough to store small datasets, but for larger datasets dedicated file formats and relational databases with geographic extensions are commonly used. Such extensions add additional data types for storing coordinates in a normal relational database table and add support for querying based on geographic properties. In this paper we use two file formats and a relational database.

Because of the simple unified data model of layers, points, lines and polygons it is straightforward to create maps with multiple layers in which the data of the different layers comes from different data sources, even using different coordinate reference systems. As long as you can select coordinates and map them to a common reference systems you can combine layers in a single map. Many GIS tools allow you to combine information in this way.

Styling and Drawing maps

To draw a map from geographic data we need a program that takes all the geographical features as input and computes where and how they should be drawn on a two-dimensional canvas. To do so, a database with geographic

Figure 2. Zoom level 0: The whole earth on a single tile

features alone is not enough. Whether we use an interactive GIS or a batch program that renders a map to a file, we need to specify additional information. For lines, we have to decide what color, or shade of gray they have to be. We also have to know how thick they should be and what type of lines they should be. Dotted, dashed or solid for example. For points, we need to draw some kind of marker. This can be a simple dot, or a complicated image. Either way you need to specify what points will look like. For polygons, we also need to define how they will be drawn. This could again range from a simple solid fill color, to a complex shading or gradient. A final styling issue that we should mention is the styling of labels. Maps often contain textual labels on the map itself. Labels are used for things like street names, city names or other noteworthy features. A map rendering program needs to know how to draw them. It needs to know what fonts and colors to use, and where to align the labels in relation to the feature.

What is possible in terms of styling depends on the software you use, but to understand the map rendering toolchain it is important to know that map rendering typically needs these two orthogonal types of information. What features to draw on the map, and how to style them.

Slippy Maps

The previous sections have introduced concepts that apply to all types of maps. In this paper we are primarily interested in maps for web-based applications. The way these typically deal with maps is different from desktop GIS applications. Typical online maps you may be familiar with, such as Google maps or the `openstreetmap.org` home page, use a technique for creating maps called a slippy map. In these maps only a few layers of the map are dynamically rendered in the web browser. These layers contain the dynamic parts of the map, such as the locations of your search result, or a visualization of a proposed route. All other layers (landmasses, streets, buildings etc.) are rendered in aggregation by a server and downloaded by the browser as a collection of images. These images are called "tiles" and are typically 256 by 256 pixel images. The map application in the web browser only downloads the necessary tiles for the region of the map the user is looking at, and stitches them together to create a single bitmap layer. This so called "base layer" is an efficient way to offload the computationally expensive rendering to a centralized server. Another advantage of this approach is that the tiles do not need to be rendered every time a browser needs them, but can be cached as pre-rendered images. Tile images and the libraries and applications that use them use a standardized format. This format is based on a three-dimensional coordinate system. The first dimension is the zoom level. On the lowest zoom-level, level 0, the map of the entire earth fits on a single square tile (See figure 2). When zooming in a level, both the width and height of the map are doubled. This means that at zoom-level 1, the whole map fits on a 2x2 grid of 4 tiles. At zoom-level 2, a 4x4 grid of 16 tiles is used and so on. The remaining dimensions (x and y) are needed to indicate the column and row on the grid for the given zoom level. When requesting tiles from a server a standard pattern is used for URL's. Tile images are requested as URL's that end with `<zoom>/<x>/<y>.png`. For example the URL `http://tiles.example.com/4/3/2.png` refers to the tile at the second row in the third column at zoom level four. This standard pattern makes it possible to use standard web servers to serve the tiles as long as the images are organized in the right directory structure. When using the tiles, the Javascript slippy map libraries compute which tiles are needed to stitch together the piece of the map they want to display.

It is important to note that in this scheme, the number of tiles quadruples at every zoom level. This exponential growth means that at detailed zoom levels, the amount of images for the entire planet becomes unfeasible large to render in advance. For tile servers that provide such large numbers of tiles, such as the main OpenStreetMap tile

servers, specific web server software is used that renders tiles on demand, but caches tiles that have been requested before. When the area you want to cover is not that large, pre-rendering a collection of tiles is possible and is a simpler strategy.

A statically rendered base map usually serves as the lowest layer of a dynamic map. In an application that uses this map you typically can add dynamic layers that contain the the objects that are relevant to the application domain on top of it. All of the common slippy map libraries allow you to this.

THE TOOL-CHAIN

The goal of the tool-chain we explain in this paper is to create a pre-rendered tile-layer that can be used locally. We approach this by illustrating how to replicate a relevant subset of the collection of tiles that make up the OpenStreetMap "Standard Tile Layer" (OpenStreetMap Contributors 2018c). We largely use the same tools as are used by the main tile servers of `openstreetmap.org`. These official tiles are created using definitions from the openstreetmap-carto project (Allan et al. 2018). Because this is our starting point, we often refer to tools or resources found in the public repository of this project troughout this section.

In the remainder of this section, we explain the tasks that need to be completed to accomplish our goal without going into specifics. We do not show the exact details of the programs and scripts that need to be executed. These details can be found in "Appendix: Script",

Preparing Basic Infrastructure

To create the tile collection we do not use a single integrated tool. The tool-chain consists of different programs and scripts that tie them together. Most of those tools work on multiple operating systems and do not necessarily need to be deployed together on a single machine. For sake of simplicity we assume a single machine configuration running the Ubuntu Linux 18.04 operating system. On this Linux distribution most of the software we use is available in its standard package repositories. It is also the operating system on which we have tested and used the tool-chain.

Aquiring Geographic Data

The first thing we need is the geographic data that will be put on the map. There are various providers of open geographic data that publish free datasets. Because we are recreating the OpenStreetMap tiles, the primary data set we use is the OpenStreetMap database. The full database is available from `planet.openstreetmap.org`, but is fairly large (43GB at the time of writing). Depending on your application, you may not need data for the entire planet. In that case you can download an extract from a provider such as GeoFabrik (Geofabrik GmbH 2018) that offers many regional extracts.

To exactly recreate the standard OpenStreetMap tiles, just the OpenStreetMap data is not enough. We need several additional data sets from Natural Earth (*Natural Earth* 2018). These provide relatively static features such as as country borders and land masses. We also need a set of preprocessed data that is derived from the main OpenStreetMap data. These contain, for example, coast-line polygons that are simplified to create smoother maps at lower zoom levels. The openstreetmap-carto repository contains a script that automates downloading and indexing these additional data sets.

Aquiring Additional Style Resources

As explained in section "Preliminary Concepts", we also need styling definitions, marker images and fonts to be able to render the map. With the exception of the fonts, these are all included in the opentreetmap-carto repository. The fonts used in the style definitions should be installed on the operating system such that the map rendering tools can find them.

Storing and Preparing the Geographic Data

The tool that actually renders the map cannot work with the distributed form of the OpenStreetMap database directly. The planet dataset (or an extract) is published in a compressed format that is optimized for distribution. It is not structured to allow efficient querying of the data which is needed to create the map. To use the data it needs to be stored in a form that can be easily queried. The standard solution for doing this with openstreetmap data is to use the PostgreSQL database management system (The PostgreSQL Global Development Group 2018) with the PostGIS (PostGIS Contributors 2018) extension. Using a tool called "osm2pgsql" you can import an

openstreetmap dataset into a PostgreSQL database. When used on an empty database it will create a standardized database schema to import the data to. To create the standard tiles the osm2pgsql import tool is run with a customized script from openstreetmap-carto that filters and and transforms the data during import. Data from the data set that is not shown on the map is not even imported into the database. This is efficient, but also means that it limits your ability to customize the map later on.

The additional datasets are in "shape file" format and do not need additional processing. They can be used by the map rendering software directly.

Preparing the Map Style Configuration

The last piece of preparation that needs to be done is to create the configuration that will drive the map rendering process. Which layers will be drawn on the map, what data is needed for those layers and how the layer will look needs to be defined. The rendering tool, that is explained in the next section, relies on a single XML document as its configuration. For tiles as complex as the openstreetmap standard tiles, writing such a single document directly is not very user friendly. CartoCSS (MacWright et al. 2018) is a style language very similar to Cascading Style Sheets (CSS), the standard for styling web pages. The openstreetmap-carto project uses the CartoCSS language to define the style of the tiles in a modular collection of style files. A special compiler named "carto" is used to translate these CartoCSS styles into the XML document needed for rendering.

Rendering the map

Rendering the map, the creation of the collection of tile images, is done using a tool called "Mapnik" (Pavlenko 2018). Unlike the other tools in the chain, Mapnik is not a standalone program. Mapnik is a software library that you can use in your own programs. It provides interfaces for different programming languages, but we only need the interface for the Python programming language. More specifically, we customize a Python script from the OpenStreetMap project (OpenStreetMap Contributors 2018a) that uses Mapnik to render a collection of tiles. This script is exactly what we need to achieve our main goal. By default the script creates tiles for a number of hardcoded example regions. To use the script, the only additional step is to replace these regions by the regions that we want to create maps for.

Testing the Map

The last stage of the tool-chain is using the tiles in a web application. This requires two components. The first is a slippy map Javascript library that ties the dynamic data from your web application to a static tile-based layer. To test the maps we use Leaflet (Agafonkin 2018). This slippy map library is also used on the main `openstreetmap.org` website. Embedding a Leaflet map in a webpage is straightforward and the Leaflet website offers examples on how to create a map and add tile-based layers. The second component needed to test the map is a basic webserver to serve the tiles, the leaflet library and a web page that glues them together. Because the collection of tiles is just a directory structure of image files, it can be served by any web server software.

Using the Map

In the original Incidone use case, and in other applications where we used these tools, we used the iTask Framework. (iTasks Contributors 2018) This framework comes with a built-in web server that can serve the pre-rendered tiles. It also provides tight integration with the Leaflet library that enables the manipulation of the maps through an abstract datastructure without the need to program the low-level Javascript details. Similar integrations are available for other programming languages and web-application frameworks.

EXERCISES

The intend of this paper is to help you understand the tool-chain, and to enable you to customize it to the needs of your applications. In this section we provide some exercises to challenge you to explore and learn how to use the tools.

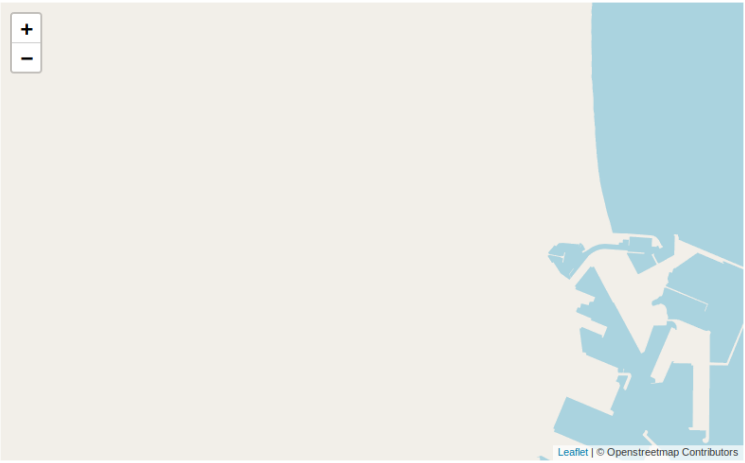


Figure 3. A mimimal rendering without the openstreetmap data

Set up the tools

The first exercise is to actually get the toolchain set up, to generate some tiles, and to view them in a simple web page. To help you get started we have created a basic shell script that executes all the necessary steps to set up the tools, to download the required data, and to render a first map. It is included as an appendix to this paper in "Appendix: Script".

With this script you should do the following:

- Prepare a machine running Ubuntu Linux 18.04,
- Download the script,
- Run the script, or to learn what's involved, execute all the steps in the script manually.

When succesful, you now have a basic set up for creating tile collections that you can change to your liking.

Simplify the Map

The standard OSM tiles contain many layers. Their definition may be overwhelming at first. In this exercise the goal is to reduce the map to the bare minimum and remove all the layers that use the OSM PostgreSQL database. To do this:

- Find the file that defines the layers of the openstreetmap-carto style,
- Figure out which layers are created from the shapefiles and which are created from the PostgreSQL database;
- Create a copy of the file with all the database-based layers removed;
- Create a Mapnik stylefile from this copy;
- Re-generate the tile collection with this alternative style.

When you test your map, you should now only see a basic map without any streets, buildings etc. as shown in figure 3.

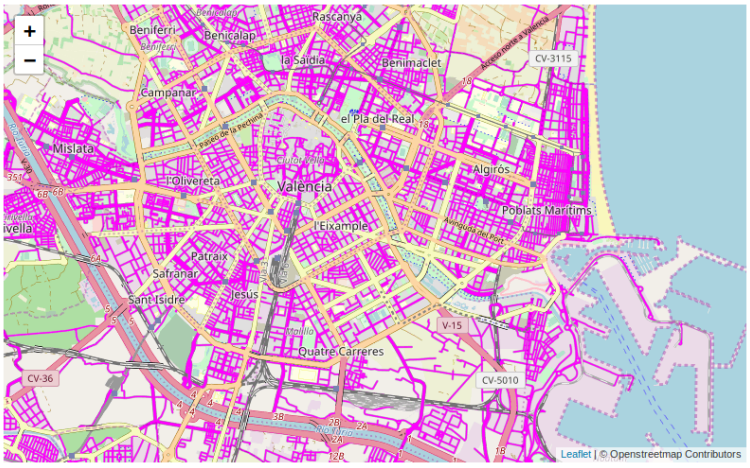


Figure 4. A brightly colored alternative map styling

Change the Map Style

The OpenStreetMap standard layer is a well designed map, but your own local maps can look any way you want. By using the openstreetmap-carto style as a starting point you can tune it to your liking. In this exercise the goal is to change the way a common feature is rendered.

- Find out where the color of city streets is defined;
- Change the color to something bright and recognizable;
- Re-create the Mapnik stylefile;
- Re-generate the tile collection with this alternative style.

Your map should now be rendered with your new favorite color, similar to figure 4.

Change the Map Data

When you have followed the script, your database will now contain (part of) an up-to-date OpenStreetMap data set. Having a local copy of this data allows you to modify it before you render your maps. In this exercise the goal is to explore the PostgreSQL database and modify or remove some of the data.

- When viewing your map, choose a point of interest. For example a streetname or building;
- Figure out how this feature is represented in the PostgreSQL database;
- Update or remove those records from the database;
- Re-generate the tile collection.

For example, in figure 5 you see a map of the city of Valencia that has been aptly renamed for the occasion.

RELATED WORK

The amount of open source tools for working with geographic information is very large. The tool chain presented in this paper is just one of many possible options for adding private maps to web applications. A large part of the specific setup of this toolchain is based on the installation instructions of openstreetmap-carto, because we chose to take the current version of the openstreetmap tiles as our starting point.

In this paper we explicitly focused on creating pre-rendered tile collections because of their simplicity, and because they are easy to deploy as bundled assets with a web application. If you are instead interested in creating a dedicated tile-server with on-demand rendering and caching of tiles, the “Manually building a tile server” guides from switch2osm.org (Fairhurst 2018) are a good starting point.

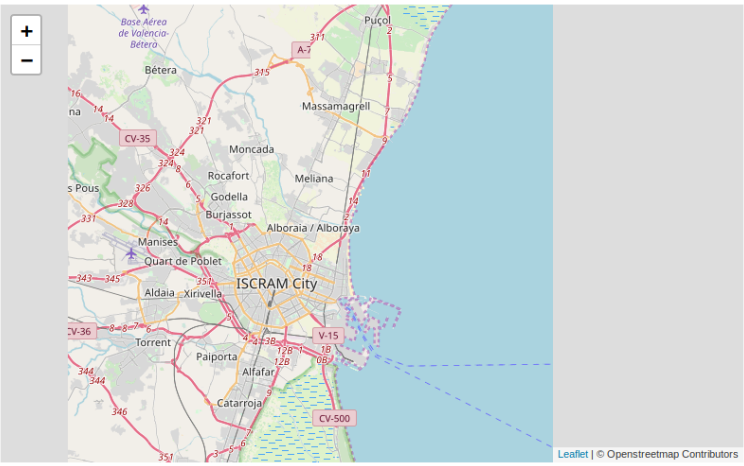


Figure 5. A custom rendering with a renamed city

The tool-chain we presented consists entirely of command line tools and scripts. This makes it very suitable for customization and automation on server machines. As an alternative, you could also use a desktop GIS application like QGIS (QGIS Contributors 2018) to define and style a map and use it to export tiles. Either through embedded scripting or by using a dedicated plugin.

This paper provides a pragmatic starting point for creating your own private maps from open data. We provide just enough background information to understand what the tools do, what their interfaces are, and how they depend on each other. It should be enough if all you need is a robust private replacement for popular third-party API's such as Google Maps. If you want to know more about cartography with open source tools, the website of the Open Source Geospatial Foundation (OSGeo 2018) is a good starting point.

CONCLUSION

In this paper we have shown the process of making your own collection of tile images from open data to use as a base layer in web-based maps. This approach enables the use of maps in web-based systems without relying on third-party online map service providers. This approach can therefore make the use of web-based maps both more private and more robust

The tool-chain to achieve this goal consists of all open source tools that are freely available. To use them together however, you need to have some background knowledge of GIS concepts thats is often implictly assumed. The aim of this paper is to explain the tool-chain, along with the necessary context, independent of specific details of the individual tools. By understanding the process and how the various pieces work together, it becomes possible to adapt to future changes in the specific tools.

Although we expect the tools to evolve, we have included a concrete example based on the tool chain at the time of writing. Additionally we have included several exercises to explore how the chain can be customized. Together with the explanation at the conceptual level, it should enable you to begin using robust private maps created from open data in your own web-based crisis management information systems.

ACKNOWLEDGMENTS

The authors of this paper are not affiliated with the authors of the tools and data sets that are being shown in this paper. We want to express our gratitude to all of these open source contributors for making their tools and data available publicly.

REFERENCES

Agafonkin, V. (2018). *Leaflet - a Javascript library for interactive maps*. URL: https://leafletjs.com/ (visited on 11/30/2018).

Allan, A., Melissen, M., Norman, P., Konieczny, M., Ko, D., Hormann, C., and Sommer, L. (2018). *OpenStreetMap Carto*. URL: https://github.com/gravitystorm/openstreetmap-carto (visited on 11/30/2018).

Fairhurst, R. (2018). *Manually building a tile server*. URL: https://switch2osm.org/manually-building-a-tile-server-18-04-lts/ (visited on 11/30/2018).

Geofabrik GmbH (2018). *OpenStreetMap Data Extracts*. URL: http://download.geofabrik.de/ (visited on 11/30/2018).

Gilman, D. and Baker, L. (Oct. 2014). "Humanitarianism in the Cyberwarfare Age - OCHA Policy Paper 11". In:

iTasks Contributors (2018). *iTask Framework*. URL: http://www.itasks.org/ (visited on 11/30/2018).

Lijnse, B., Jansen, J., and Plasmeijer, R. (Apr. 2012). "Incidone: A Task-Oriented Incident Coordination Tool". In: *Proceedings of the 9th International Conference on Information Systems for Crisis Response and Management, ISCRAM '12*. Ed. by L. Rothkrantz, J. Ristvej, and Z. Franco. Vancouver, Canada.

MacWright, T., Käfer, K., Ashton, A., Springmeyer, D., and Glanznig, M. (2018). *CartoCSS*. URL: https://github.com/mapbox/carto (visited on 11/30/2018).

Natural Earth (2018). URL: https://www.naturalearthdata.com/ (visited on 11/30/2018).

OpenStreetMap Contributors (2018a). *Generate tiles Python script*. URL: https://raw.githubusercontent.com/openstreetmap/mapnik-stylesheets/master/generate_tiles.py (visited on 11/30/2018).

OpenStreetMap Contributors (2018b). *OpenStreetMap Project*. URL: https://www.openstreetmap.org/ (visited on 11/30/2018).

OpenStreetMap Contributors (2018c). *Standard tile layer*. URL: https://wiki.openstreetmap.org/wiki/Standard_tile_layer (visited on 11/30/2018).

OSGeo (2018). *The Open Source Geospatial Foundation*. URL: https://www.osgeo.org/ (visited on 11/30/2018).

Pavlenko, A. (2018). *Mapnik - the core of geospatial visualization & processing*. URL: https://mapnik.org/ (visited on 11/30/2018).

PostGIS Contributors (2018). *PostGIS - Spatial and Geographic objects for PostgreSQL*. URL: https://postgis.net/ (visited on 11/30/2018).

QGIS Contributors (2018). *QGIS A Free and Open Source Geographic Information System*. URL: https://qgis.org/en/site/ (visited on 11/30/2018).

The PostgreSQL Global Development Group (2018). *PostgreSQL: The world's most advanced open source database*. URL: https://www.postgresql.org/ (visited on 11/30/2018).

APPENDIX: SCRIPT

This section contains the script used to setup and test the toolchain verbatim. It is publicly available online at https://gitlab.science.ru.nl/baslijns/web-maps-scripts.

```
#!/bin/bash
# This scripts sets up a toolchain for rendering tile collections for
# private web-maps.
# This script assumes execution as root user on an Ubuntu 18.04 system

### Aquire geodata ###

# Make sure basic utilities are installed
apt-get update
apt-get install -y sudo wget git python nodejs npm

# Clone the openstreetmap-carto git repository
# This will be the starting point for
git clone https://github.com/gravitystorm/openstreetmap-carto.git

# Download the map primary map data
wget http://download.geofabrik.de/europe/spain-latest.osm.pbf
mkdir -p openstreetmap-carto/data

# Download and index the additional map data as shapefiles
apt-get install -y mapnik-utils
cd openstreetmap-carto
python scripts/get-shapefiles.py
cd ..

# Install and configure a PostgreSQL RDBMS with GIS extensions
# Also create a database named 'gis' that will hold the OSM data
apt-get install -y postgis
/etc/init.d/postgresql start
sudo -u postgres createuser -s root
createdb gis
psql -d gis -c 'CREATE EXTENSION postgis; CREATE EXTENSION hstore;'

# Import the primary map data into the database
apt-get install -y osm2pgsql

cd openstreetmap-carto
osm2pgsql -G --hstore --style openstreetmap-carto.style --tag-transform-script openstreetmap-carto.lua -C 1600 -d gis data/spain-latest.osm.pbf
cd ..

### Creating the tiles ###

# Create the mapnik stylesheet using the carto compiler
npm -g install carto
apt-get install -y fonts-noto-cjk fonts-noto-hinted fonts-noto-unhinted ttf-unifont

cd openstreetmap-carto
carto project.mml > osm.xml
cd ..

# Install the mapnik library and the python bindings
apt-get install -y python-mapnik

# Download a script that renders batches of tiles
wget https://raw.githubusercontent.com/openstreetmap/mapnik-stylesheets/master/generate_tiles.py
# Remove the generation of tiles for the example cities in the script
# and disable strict loading of the osm.xml file
head -n 216 generate_tiles.py | sed "s/mapnik.load_map(self.m, mapfile, True)/mapnik.load_map(self.m, mapfile, False)/" > custom_generate_tiles.py
# Add a city of our own (Valencia) to be rendered in detail as an example
echo "    render_tiles((-0.49,39.37, -0.24, 39.56), mapfile, tile_dir, 1, 16, \"Valencia\")" >> custom_generate_tiles.py
# Run the script to render the tiles
mkdir -p tiles
MAPNIK_MAP_FILE=openstreetmap-carto/osm.xml MAPNIK_TILE_DIR=./tiles python custom_generate_tiles.py

### Testing the map ###

# Install and configure Nginx to serve a simple web-page with a Leaflet instance
apt-get install -y nginx
npm -g install leaflet

# Configure nginx
echo "server {" >> /etc/nginx/conf.d/privatemap.conf
echo "  listen 8000;" >> /etc/nginx/conf.d/privatemap.conf
echo "  location / { root $(pwd)/tiles; index index.html; }" >> /etc/nginx/conf.d/privatemap.conf
echo "  location /leaflet { alias /usr/local/lib/node_modules/leaflet/dist; }" >> /etc/nginx/conf.d/privatemap.conf
echo "}" >> /etc/nginx/conf.d/privatemap.conf

nginx; nginx -s reload

# Create a minimal html page that serves an instance of
# the leafletjs slippy map with our map added as tilelayer
echo "<html>" >> tiles/index.html
echo "<head>" >> tiles/index.html
echo "<link rel=\"stylesheet\" href=\"/leaflet/leaflet.css\">" >> tiles/index.html
echo "<script type=\"text/javascript\" src=\"/leaflet/leaflet.js\"></script>">> tiles/index.html
echo "</head>" >> tiles/index.html
echo "<body>" >> tiles/index.html
echo "<div id=\"map\" style=\"width: 100%; height: 100%;\"></div>" >> tiles/index.html
echo "<script type=\"text/javascript\">" >> tiles/index.html
echo "var m = L.map('map').setView( [39.4633, -0.3633], 13);" >> tiles/index.html
echo "L.tileLayer('http://localhost:8000/{z}/{x}/{y}.png', {attribution: '&copy; Openstreetmap Contributors'}).addTo(m);" >> tiles/index.html
echo "</script>" >> tiles/index.html
echo "</body>" >> tiles/index.html
echo "</html>" >> tiles/index.html

# Done
echo "You can view your map at http://localhost:8000/
```

EMAssistant: A Learning Analytics System for Social and Web Data Filtering to Assist Trainees and Volunteers of Emergency Services

Rahul Pandey
George Mason University
rpandey4@gmu.edu

Gaurav Bahl
George Mason University
gbahl@gmu.edu

Hemant Purohit
George Mason University
hpurohit@gmu.edu

ABSTRACT

An increasing number of Machine Learning based systems are being designed to filter and visualize the relevant information from social media and web streams for disaster management. Given the dynamic disaster events, the notion of *relevant information* evolves, and thus, the active learning techniques are often considered to keep updating the predictive models for the relevant information filtering. However, the active relevant feedback provided by the human annotators to update the models are not validated. As a result, they can introduce unconscious biases in the learning process of humans and can result in an inaccurate or inefficient predictive system. Therefore, this paper describes the design and implementation of an open-source technology-based learning analytics system '*EMAssistant*' for the emergency volunteers or practitioners - referred as the trainee, to enhance their experiential learning cycle with the cause-effect reasoning on providing relevant feedback to the machine learning model. This continuous integration between the cause (providing feedback) and the effect (observing predictions from the updated model) in a visual form will likely to improve the understanding of the trainees to provide more accurate feedback. We propose to present the system design as well as provide hands-on exercises for the conference session.

Keywords

Training System, Disaster Management, Active Learning, Humanitarian Technology, Social Media Mining

INTRODUCTION

There is a growing number of sources sharing situational updates during a disaster event via social media as well as other web platforms such as news feeds that lead to the phenomenon of *big crisis data* (Castillo, 2016). These situational updates include time-critical reports (Imran et al., 2013) as well as requests and offers to help (Purohit et al., 2013) such as through Facebook's recently launched 'Community Help' feature. Moreover, given the ubiquitous adoption of Internet-based communication by the public, the importance of mining the big crisis data streams in the expectation of extracting the time-critical, relevant situational information to assist emergency management agencies has grown tremendously in the recent years (U.S Homeland Security, 2014; Hughes and Palen, 2012; Hiltz et al., 2014; Meier, 2015). Also, as per recent surveys (Reuter and Spielhofer, 2017; Canadian Red Cross, 2018), there is a growing expectation by the public to seek a response from the emergency services through an online medium, especially social media. However, the characteristics of big crisis data like high volume, velocity, and variety issues can create a challenge of timely extracting situational information from social and web data streams.

Researchers in the crisis informatics and disaster management have investigated many approaches in the last two decades to understand, process, and manage the streaming big crisis data, in order to provide systematic access to the relevant information (*c.f.* survey Imran et al., 2015). The analytical approaches primarily include

mining user-level information (e.g., onsite witnesses (Starbird et al., 2012), trustworthiness (Tapia et al., 2011)), content-level information (e.g., topical categories (Imran et al., 2013), help behavior (Purohit et al., 2014)) as well as network-level (e.g., retweetability prediction (Neppalli et al., 2016)) and context-level (e.g., location (Al-Olimat et al., 2018)) information.

There have been several efforts in the last decade to develop systems that implement the above-discussed analytical approaches for assisting emergency management organizations. Such existing analytics systems incorporate multiple data sources and often with different modalities to study a disaster event in real time as well as retrospective view (e.g., TweetTracker (Kumar et al., 2011), Twitcident (Abel et al., 2012), CrisisTracker (Rogstadius et al., 2013), Truthy (McKelvey and Menczer, 2013), AIDR (Imran et al., 2014), Twitris (Sheth et al., 2017), CitizenHelper-Adaptive (Pandey and Purohit, 2018)).

However, the majority of the existing systems rely on the prebuilt machine learning models using the datasets from the prior events alone to train and set up the analytical system for a current event. It is because there are very few training data instances available at the onset of a new disaster event to build a robust machine learning model. For overcoming that, researchers have used active learning techniques to frequently update the prebuilt model with expert feedback for addressing the performance issue of the misprediction in continuous data streams (e.g., CitizenHelper-Adaptive (Pandey and Purohit, 2018); AIDR (Imran et al. 2014)). However, due to the increasing workload of the expert emergency management professionals during time-critical crisis operation, it is challenging to learn to provide effective feedback for relevant information at the same time. Additionally, given the increasing trends of leveraging help from crowdsourcing, they want to rely on operationally non-expert volunteers to do this task of providing relevance feedback on the data stream to improve the machine learning based information filtering system. Thus, covering all the aspects of training the practitioner trainees as well as volunteers can be costly both in terms of money and time for the emergency services.

Thus, we address two key problems in our proposed system design. First, the input data stream is sometimes hard to comprehend due to the changing definition of relevance (issue of concept drift), which can be mitigated by frequently informing the trainee through the effects of providing feedback to a diverse set of message instances from the ground truth. Second, the trainee/volunteer may possess certain bias in learning the patterns of what constitutes a relevant message as reflected in the feedback provided by him/her, which can be mitigated by showing the trainee/volunteer the performance of the updated (weak) prediction model frequently.

We propose *EMAssistant — Emergency Management Assistant*, an open source technology-based learning analytics system that will assist emergency management trainees to provide accurate feedback in improving a machine learning model for information filtering tasks. The system provides a web-based learning platform for the trainee by constantly re-training the model from the feedback provided by them and then visualizing a few expert-labeled data based on the error comparison of its predicted and original labels. We are also utilizing expert-labeled data along with the trainee's feedback for robust re-training of the model. As soon as the trainee observes that the error effect has been minimized consistently, they will be ready to provide the feedback in a real-time environment and contribute to the data-driven disaster management information filtering tasks. The resulting system is cost effective since it can be adapted to any social media mining problem beyond the information filtering task for the emergency services; for example, in training the student practitioners for data analytics with the state-of-the-art techniques. The rest of the paper is organised as follows. We first discuss related work on the systems designed for disaster management. We then describe the design of our proposed system architecture, followed by the analysis of the proposed tool with an illustration of the system's functionality using a past disaster event dataset. The conclusion summarizes our plan for the demo, exercises during the conference session, as well as the directions for future upgrades for the system.

RELATED WORK ON DISASTER ANALYTICS SYSTEMS

We describe state-of-the-art tools in the crisis informatics and disaster management literature.

Recent advancement in technologies has brought more engagement during emergency and disaster management for the emergency practitioners, the crowdsourcing volunteers, and the affected communities. This has led to the flood of shared information on social and web platforms that can be utilized to do what was earlier not possible in disaster management. However, since most of the incoming data is unstructured, many research works have been done to extract semantically structured information (Garcia-Santa et al, 2015).

I-REACT (I-REACT Project, 2018) is an example of one such platform that uses both mobile and web platforms to offer better anticipation of extreme weather events, floods, and fire with historical knowledge, satellite and risk maps, crowdsourced reports, and social media information. In addition, many crowdsourcing tools are used for extracting the relevant information from unstructured data streams that include a variety of methods, such as natural language understanding, multisource data collection, filtering, tagging, mapping and navigation, volunteer management, and crowdsourcing roles tools. Prior work on web-based, as well as mobile-based platforms, can be classified into 4 categories based on tools functionality: Crisis Mapping, Crisis Navigation, Volunteer Management Tools, and Ontologies (Poblet et al., 2017).

Among the web-based platforms, Twitris (Sheth et al, 2014) and iCoast (Liu et al., 2014) are two examples used for crisis data analytics and crisis mapping. Twitris involves real-time analysis of social sensing and perception for disaster response including earthquakes, hurricanes, tornados, and floods. iCoast gives a platform to volunteers to upload an informative aerial photograph of the affected area in a disaster event for crisis mapping. For crisis navigation, OSMTracker is a mobile-based application that collects track logging and navigational information from users. Similarly, many tools are available for volunteers management like GeoTag-X (Jennett & Cox, 2014), CrowdCrafting (Sánchez de Miguel et al., 2015), Micromappers (Ofli et al., 2016), Tomnod(Lin et al,, 2014), and Verily (Meier et al., 2013). GeoTag-X, for example, uses volunteers to analyse photo taken in disaster-affected areas, while Crowdcrafting is used in the analysis of data or challenging tasks with the help of volunteers. Furthermore, Micromappers uses human intelligence to get semantic information from unstructured data and Tomnod asks volunteers to identify important objects in satellite images during the crisis. In addition, Verily helps to mitigate false information spread during a disaster with the help of crowdsourcing volunteers. There are also mobile-based crowdsourcing tool like UN Assign (Bæhr, 2016), FemaApp, and FirstToSee that are used for crisis mapping by allowing the user to upload geotagged pictures in the disaster-affected area. Finally, AIDR (Imran et al., 2014) - Artificial Intelligence for Disaster Response provides a platform to create ontologies. It is then used to perform automatic classification of messages that people post during disasters into given ontologies for large-scale data at high speed.

We can observe that a lot of the existing systems depend on volunteer's contributions. Yet, there are no prior systems that tackle another core functionality of crisis management platform i.e. learning analytics system to these volunteers. Most of the system assumes that the volunteers either have significant knowledge or are trained before for better interacting with the system. However, it is not always the case and training volunteers on a large scale can be very expensive. That's why our proposed method will not only help train volunteers in scale but also in a cost-effective way. The little involvement of the humans in the proposed system makes it scalable. Figure 1 shows the architecture of our system and Figure 2 shows an illustration of our main system of providing the feedback and observing the effects respectively.

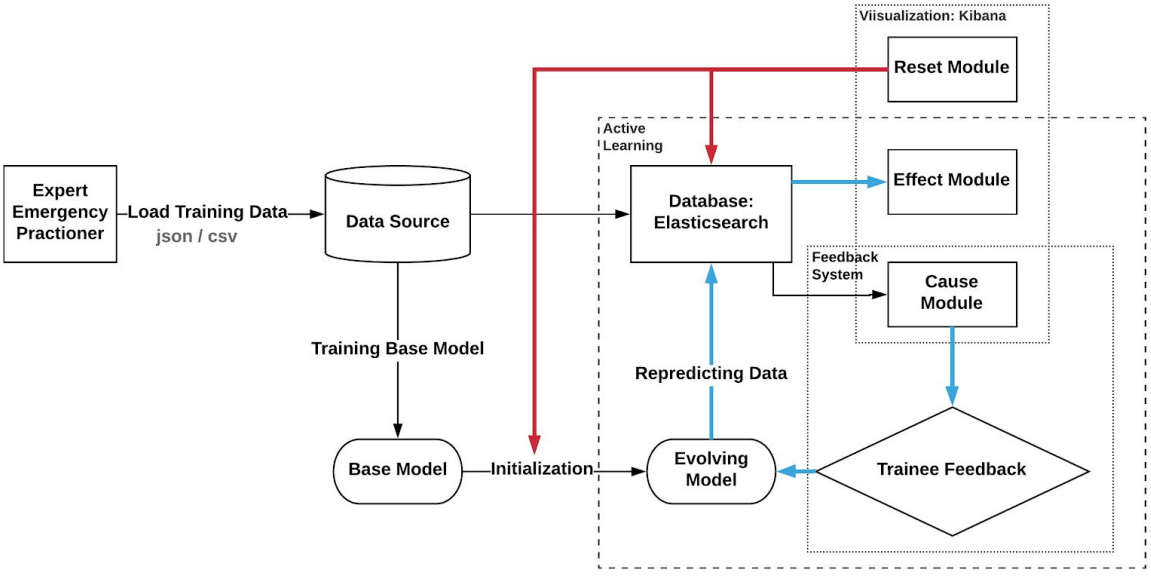


Figure 1. System architecture of EMAssistant

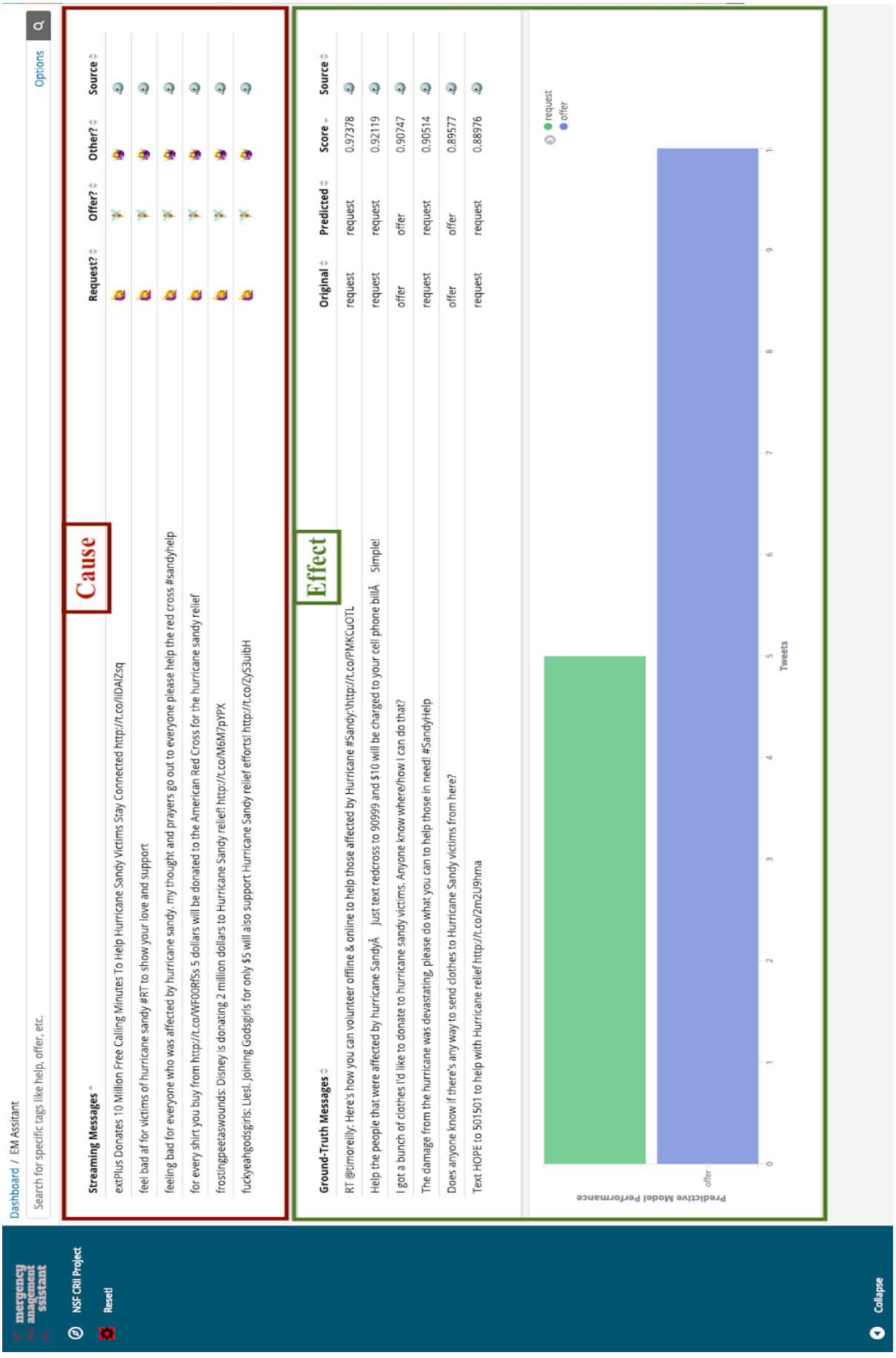


Figure 2. Illustration of analysis using EMAssistant system feedback

EMERGENCY MANAGEMENT ASSISTANT SYSTEM (*EMAssistant*)

This section describes the architectural pipeline for various features of the proposed *Emergency Management Assistance System* which provides a training mechanism to emergency practitioners using active machine learning capabilities. The system architecture of EMAssitant is shown in Figure 1. It consists of 4 main modules: *Data Loading, Training Model, Active Learning, and Visualization*. The blue arrow indicates the feedback-based model re-training cycle and the red arrow shows the effects of the reset functionality on the database and base model initialization.

A. Data Loading

We used the expert labeled data collected from Emergency Practitioners (EM). These labels in the data act as ground truth for training the model. The data is then loaded in the ElasticSearch Database. While loading the data, few of the data points were marked to observe and visualize the effects in the *Ground Truth Visualization* and *Predictive Model Performance Visualization* components of Kibana.

Both Elasticsearch and Kibana are open source projects where Elasticsearch is a searching and analytics engine that provides distributed, RESTful, JSON based search engine that makes it highly scalable and flexible for a large amount of data. On the other hand, Kibana lets us visualize data in the form of various dashboards which includes graphs and table. We have integrated stacked bar chart under *Predictive Model Performance Visualization* which assists the trainee to efficiently visualize the per class effects based on the feedback provided. Kibana and Elasticsearch work exceptionally well together and provides rapid deployment for a variety of custom visualizations as needed for various EM exercises. Kibana also provides scripted fields that can help to create custom URL links for each message object. We have used this feature to generate URLs to call an API and it acts like a button in the enhanced-table visualization that is used by both *Streaming Message Visualization* and *Ground Truth Visualization*. Trainee uses these buttons to give feedback as a result of which our API is called, which re-trains the model and update the *Ground Truth Visualization*. One more reason to choose Kibana was that the dashboards created under Kibana are automatically refreshed after every 5 seconds, thus provides a real-time visualization of the effects as per the feedback provided by the trainee.

B. Training Model

Based on the expert labels provided by the Emergency Practitioners we build a model to classify high-level content and behavior information, such as intents like request or offering help during crisis management. We first create a base model that is trained on the initial expert labels. We have ignored the messages marked for *Ground Truth Visualization for training*. For the features generation, we have used the traditional *Bag of Words* (BoW) features (Witten et al., 2016) and for training, we have used a linear logistic regression model. Now once the adequate feedback is provided, we create an evolving model from the initial training data with the updated labels (from feedback) using the same parameters of linear logistic regression classifier. This evolving model is then used to predict the intent label of the data points that were marked for *Ground Truth Visualization*.

C. Active Learning

We have designed a feedback-based active learning approach for the trainee to continuously learn based on visualizing the cause and effect due to the feedback provided on the training model. For instance, considering the data in an emergency situation, whether the incoming messages are classified as a request, offer or other intent. For making the model train and evolve actively, the trainee will first provide the feedback in the *Streaming Message Visualization* and then observe the effects under *Ground Truth Visualization*. More specifically, we have used two parameters in our ground truth messages visualization: original and predicted. Based on the feedback provided by the trainee, the system will update the training data with the new labels and retrain the model. We use this evolving model to re-predict the data existing in the *Ground Truth Visualization* table and store the updated labels in *Predicted* column whereas the *Original* column remains the same. In this way, the trainee can see the effects of the updated model through comparison between predicted labels and original ground truth labels under *Ground Truth Visualization* table. Every time based on the volunteer action, the model will be retrained and changes will get reflected in the dashboard, which acts as a continuous learning process until the trainee observes no change in the original and predicted values and that's how bias possessed by the trainee will be removed and the trainee is ready to provide accurate feedback in real time operational environment.

D. Visualization

We have used the Kibana visualization framework for interacting with the analyzed data. Figure 2 represents our system's visualization. Our visualization has been divided into four main sub-components.

1. Streaming Message Visualization
2. Ground Truth Visualization
3. Predictive Model Performance Visualization
4. Reset Functionality

1. *Streaming Message Visualization*: This visualization will provide an interface for the volunteer to provide feedback on the messages and annotate it as a relevant label category. It contains 5 columns. The first column represents the text that shows the message text. Second, third, and fourth columns show a link to provide the feedback of request, offer, or other intent categories respectively. Finally, the fifth column contains the link to the original Twitter source of the message.

2. *Ground Truth Visualization*: This visualization will act as a learning interface for the trainee where one will see the impact of the feedback provided under the *Streaming Message Visualization*. Each message under this visualization will show the original and predicted values where original stores the ground truth and predicted stores the labels predicted by the re-trained model. Apart from these, the score field will store the confidence score calculated by the prediction probability method of the model for each message in which the higher average scores of correct predictions represents better feedback provided. The volunteer will keep on providing feedback until the original and predicted labels become the same and the overall average confidence score increases or reach to its *best* possible value.

3. *Predictive Model Performance Visualization*: This is represented through a stacked bar chart visualization that displays out of each ground truth labels, how many were correctly predicted in the intent label.

4. *Reset Functionality*: Volunteer can go back to the initial stage of learning using the reset button. This will take the model back to its initial stage and reset the intent label back to the ground truth label in the Elasticsearch as a result, the evolving model will be replaced by the base model.

ILLUSTRATION OF LEARNING ANALYTICS USING *EMAssistant*

For the analysis, we have used data collected from Twitter for Hurricane Sandy, which was the most destructive hurricane of 2012 in Atlantic. Our aim is to teach volunteers to provide feedback if the messages can be classified as the intent of requesting help, offering help, or none (Pandey and Purohit, 2018). We have labels validated from emergency experts and crowdsourcing workers or volunteers that will help build the base model to compare the effects. The reason why we have taken these intent labels is due to the fact that they can induce concept drift. For example, tweet like *"I am 9 ft above water levels, why am I told to evacuate now? Please advise"* is of a request for rescue intent category. On the other hand, tweet like *"Wow didn't realize how bad this hurricane was. #SandyHelp donate 10 dollars to help. Text REDCROSS to 90999"* is of a request for donation intent category. We can observe that even both the message should be under the *request* intent category, their semantics are different. These concept drifts can confuse the trainee and make it hard for them to comprehend and classify both the type correctly as "request" intent in the first go. Thus, to overcome this challenge, our learning analytics system helps the trainee to understand this change in concepts by providing a diverse message to get feedback and observe the effects continuously until they learn. As a result, we propose a case study where we visualize the effects of the feedback provided on the machine learning model. For illustration, we will visualize the *Ground Truth Visualization* to observe the comparison between original and predicted intents and the scores by which the intents have been predicted. We have provided 3 snapshots of the *Ground Truth Visualization*, which represents the effect due to "bad", "good", and "best" feedback respectively. The *Ground Truth Visualization* constitutes of 5 fields: *Tweet Messages*: displays the incoming messages, *Original*: displays the ground truth label associated with message, *Predicted*: displays the predicted intent label based on the updated model from feedback, *Score*: displays the confidence score of the predicted intent label, and *Source*: which redirects to Twitter for that specific message. Figure 3 represents the *Ground Truth Visualization* due to *"bad"* feedback. As we can see, apart from the 4 tweet messages of *offer* intent category, every other message has been incorrectly classified to *other* intent category. Even the ones that are classified correctly, have very low confidence score. In Figure 4, which represents the *Ground Truth Visualization* due to "good" feedback, we can see that every message has been correctly classified. The overall confidence score is also much higher as

compared to the *"bad"* feedback. Finally, in Figure 5, which represents the *Ground Truth Visualization* due to the "best" feedback, we can see every message has been correctly classified with high average confidence score compared to the one due to *"good"* feedback (Figure 4). The trainee will continue to be in a situation corresponding to any of the 3 effects until they reach a point when they will finally observe the effects due to *"best"* feedback consistently and thus, will get trained.

Tweet	Original	Predicted	Score	Source
Consider donating to the Red Cross or another org to help the people affected by Hurricane Sandy. Over 60 dead. http://t.co/QWwpQzyz	request	other	0.76122	
Help the people that were affected by hurricane SandyÂ Just text redcross to 90999 and $10 will be charged to your cell phone billÂ Simple!	request	other	0.74769	
Text HOPE to 501501 to help with Hurricane relief http://t.co/2m2U9hma	request	other	0.68979	
Does anyone know if there's any way to send clothes to Hurricane Sandy victims from here?	offer	other	0.67148	
The damage from the hurricane was devastating, please do what you can to help those in need! #SandyHelp	request	other	0.67070	
does anyone know if there a local drop-off center in frederick to donate clothes to victims of hurricane sandy??	offer	other	0.64715	
Does anyone know anyways to volunteer / help hurricane sandy victims. #replytweet	offer	other	0.63518	
RT @SocialKristen: Does anyone know where in westchester I can bring clothes/donations for hurricane victims? #HurricaneSandy #helpsandy ...	offer	other	0.62326	
RT @timoreilly: Here's how you can volunteer offline & online to help those affected by Hurricane #Sandy:\http://t.co/PMKCuOTL	request	other	0.59943	
I want to donate clothes for Hurricane Sandy Relief. I just need time find out where.	offer	offer	0.56512	
I want to donate blood to the hurricane victims but it hasn't been long enough since my last donation ?? #thestruggle	offer	offer	0.55462	
@JENNIWOWW Hey girl! I have TONS of cute shoes & purses I want to donate to hurricane victims - do you know where I can send them? #Sandy	offer	offer	0.54578	
I have clothes that I'd like to donate to Hurricane Sandy victims, anyone know of drop off places for me to take them to in Jersey/NY?	offer	offer	0.51486	
I want to raise money to help the victims of Hurricane Sandy	offer	other	0.49353	
I got a bunch of clothes I'd like to donate to hurricane sandy victims. Anyone know where/how I can do that?	offer	other	0.47025	

Figure 3. Case Study: Effect table due to *"bad"* feedback for Intent classification in Hurricane Sandy

Tweet	Original	Predicted	Score	Source
RT @timoreilly: Here's how you can volunteer offline & online to help those affected by Hurricane #Sandy:\http://t.co/PMKCuOTL	request	request	0.96871	
I got a bunch of clothes I'd like to donate to hurricane sandy victims. Anyone know where/how I can do that?	offer	offer	0.92516	
Help the people that were affected by hurricane SandyÂ Just text redcross to 90999 and $10 will be charged to your cell phone billÂ Simple!	request	request	0.91010	
The damage from the hurricane was devastating, please do what you can to help those in need! #SandyHelp	request	request	0.89985	
Does anyone know if there's any way to send clothes to Hurricane Sandy victims from here?	offer	offer	0.89145	
Text HOPE to 501501 to help with Hurricane relief http://t.co/2m2U9hma	request	request	0.88794	
RT @SocialKristen: Does anyone know where in westchester I can bring clothes/donations for hurricane victims? #HurricaneSandy #helpsandy ...	offer	offer	0.86222	
I want to donate blood to the hurricane victims but it hasn't been long enough since my last donation ?? #thestruggle	offer	offer	0.84954	
does anyone know if there a local drop-off center in frederick to donate clothes to victims of hurricane sandy??	offer	offer	0.84895	
Consider donating to the Red Cross or another org to help the people affected by Hurricane Sandy. Over 60 dead. http://t.co/QWwpQzyz	request	request	0.83761	
I have clothes that I'd like to donate to Hurricane Sandy victims, anyone know of drop off places for me to take them to in Jersey/NY?	offer	offer	0.82580	
@JENNIWOWW Hey girl! I have TONS of cute shoes & purses I want to donate to hurricane victims - do you know where I can send them? #Sandy	offer	offer	0.79729	
I want to donate clothes for Hurricane Sandy Relief. I just need time find out where.	offer	offer	0.76665	
Does anyone know anyways to volunteer / help hurricane sandy victims. #replytweet	offer	offer	0.75840	
I want to raise money to help the victims of Hurricane Sandy	offer	offer	0.60367	

Figure 4. Case Study: Effect table due to *"good"* feedback for Intent classification in Hurricane Sandy

Tweet	Original	Predicted	Score	Source
RT @timoreilly: Here's how you can volunteer offline & online to help those affected by Hurricane #Sandy:\http://t.co/PMKCuOTL	request	request	0.97386	
Help the people that were affected by hurricane SandyÂ Just text redcross to 90999 and $10 will be charged to your cell phone billÂ Simple!	request	request	0.92181	
The damage from the hurricane was devastating, please do what you can to help those in need! #SandyHelp	request	request	0.90814	
I got a bunch of clothes I'd like to donate to hurricane sandy victims. Anyone know where/how I can do that?	offer	offer	0.90686	
Does anyone know if there's any way to send clothes to Hurricane Sandy victims from here?	offer	offer	0.89312	
Text HOPE to 501501 to help with Hurricane relief http://t.co/2m2U9hma	request	request	0.88886	
RT @SocialKristen: Does anyone know where in westchester I can bring clothes/donations for hurricane victims? #HurricaneSandy #helpsandy ...	offer	offer	0.85414	
does anyone know if there a local drop-off center in frederick to donate clothes to victims of hurricane sandy??	offer	offer	0.85344	
Consider donating to the Red Cross or another org to help the people affected by Hurricane Sandy. Over 60 dead. http://t.co/QWwpQzyz	request	request	0.84581	
I want to donate blood to the hurricane victims but it hasn't been long enough since my last donation ?? #thestruggle	offer	offer	0.84296	
I have clothes that I'd like to donate to Hurricane Sandy victims, anyone know of drop off places for me to take them to in Jersey/NY?	offer	offer	0.82696	
@JENNIWOWW Hey girl! I have TONS of cute shoes & purses I want to donate to hurricane victims - do you know where I can send them? #Sandy	offer	offer	0.79860	
Does anyone know anyways to volunteer / help hurricane sandy victims. #replytweet	offer	offer	0.76849	
I want to donate clothes for Hurricane Sandy Relief. I just need time find out where.	offer	offer	0.76196	
I want to raise money to help the victims of Hurricane Sandy	offer	offer	0.61393	

Figure 5. Case Study: Effect table due to *"best"* feedback for Intent classification in Hurricane Sandy

CONCLUSION AND EXERCISE PLAN

We have introduced a learning analytics tool *EMAssistant* to assist the trainees based on cause and effect visualizations from the data labeled by the experts during the emergency situation. The system will create a base model that will be actively re-trained from the feedback provided by the trainee. This will make the trainee adaptive to handle any upcoming emergency situation. The gradual learning process will make the trainee unbiased, which further makes them confident to provide feedback in real time environment. We plan to further design and evaluate learning modules guided by the human learning theories from educational psychology.

We will provide a hands-on of the *EMAssistant* tool during the conference session. Also, for the live demo and hands-on exercise session, we will provide the attendees different expert-labeled training datasets for many downstream applications of crisis management, such as topic classification (Olteanu et al., 2015), help intent classification (Purohit et al., 2013), and damage classification (Alam et al., 2018). A user survey will be conducted for the session attendees to provide input to improve the design, functionality, and the user experience of the system.

ACKNOWLEDGEMENT

Authors would like to thank Ganesh Nalluru from Humanitarian, Semantics, & Informatics lab for providing valuable feedback and proofreading. We also acknowledge the U.S. National Science Foundation (NSF) for partially supporting this research on social and web mining for disaster informatics through grant awards IIS-1657379 & IIS-1815459.

REFERENCES

Abel, F., Hauff, C., Houben, G.-J., Stronkman, R., and Tao, K. (2012) Twitcident. *Proceedings of the 21st International conference companion on World Wide Web - WWW '12 Companion*.

Alam, F., Ofli, F., and Imran, M. (2018) CrisisMMD: Multimodal Twitter Datasets from Natural Disasters, *ICWSM*.

Al-Olimat, Hussein S., Krishnaprasad Thirunarayan, Valerie Shalin, and Amit Sheth. (2018) Location Name Extraction from Targeted Text Streams using Gazetteer-based Statistical Language Models, *Proceedings of the 27th International Conference on Computational Linguistics - COLING*.

Bæhr, I. (2015) Sharing geo-information for humanitarian response and disaster management, *Geoforum Perspektiv*, 14, 26.

Castillo, C. (2016) *Big crisis data - social media in disasters and time-critical situations*, Cambridge University Press.

García-Santa, N., García-Cuesta, E., and Villazón-Terrazas, B. (2015) Controlling and Monitoring Crisis, *The Semantic Web: ESWC 2015 Satellite Events Lecture Notes in Computer Science*, 46–50.

Hiltz, S. R., Kushma, J. A., & Plotnick, L. (2014) Use of Social Media by US Public Sector Emergency Managers: Barriers and Wish Lists, *ISCRAM*.

Hughes, A. L., and Palen, L. (2012) The Evolving Role of the Public Information Officer: An Examination of Social Media in Emergency Management, *Journal of Homeland Security and Emergency Management*, *9*, 1.

Imran, M., Elbassuoni, S., Castillo, C., Diaz, F., & Meier, P. (2013) Extracting information nuggets from disaster-related messages in social media, ISCRAM.

Imran, M., Castillo, C., Lucas, J., Meier, P., and Vieweg, S. (2014) AIDR: Artificial intelligence for disaster response. *Proceedings of the 23rd International Conference on World Wide Web - WWW '14 Companion*.

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015) Processing Social Media Messages in Mass Emergency. *ACM Computing Surveys*, *47*, 4, 1–38.

Information in Disasters (2018) *Canadian Red Cross,* https://www.redcross.ca/crc/documents/Disasters_report_2018.pdf

I-REACT Project. Improving Resilience to Emergencies through Advanced Cyber Technologies Report Summary, *European Commission*, https://cordis.europa.eu/result/rcn/230055_en.html Accessed 2018-12-10.

Jennett, C., & Cox, A. L. (2014) Eight guidelines for designing virtual citizen science projects, *Second AAAI Conference on Human Computation and Crowdsourcing*

Lin, A. Y.-M., Huynh, A., Lanckriet, G., and Barrington, L. (2014) Crowdsourcing the Unknown: The Satellite Search for Genghis Khan, *PLoS ONE*, *9*, 12.

Liu, S. B., Poore, B. S., Snell, R. J., Goodman, A., Plant, N. G., Stockdon, H. F., et al. (2014) USGS iCoast -- did the coast change?, *Proceedings of the companion publication of the 17th ACM conference on Computer supported cooperative work and social computing - CSCW Companion '14*.

Meier, P. (2013) Verily: Crowdsourced Verification for Disaster Response. *iRevolutions*, https://irevolutions.org/2013/02/19/verily-crowdsourcing-evidence/

Meier, P. (2015) *Digital humanitarians: how big data is changing the face of humanitarian response*, CRC Press.

Neppalli, V. K., Medeiros, M. C., Caragea, C., Caragea, D., Tapia, A. H., & Halse, S. E. (2016) Retweetability Analysis and Prediction during Hurricane Sandy, *ISCRAM.*

Olteanu, A., Vieweg, S., & Castillo, C. (2015) What to expect when the unexpected happens: Social media communications across crises, *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 994–1009.

OSMTracker. *About OpenStreetMap - OpenStreetMap Wiki*, https://wiki.openstreetmap.org/wiki/OSMtracker

Ofli, F., Meier, P., Imran, M., Castillo, C., Tuia, D., Rey, N., et al. (2016) Combining Human Computing and Machine Learning to Make Sense of Big (Aerial) Data for Disaster Response, *Big Data*, *4*, 1, 47–59.

Pandey, R., and Purohit, H. (2018) CitizenHelper-Adaptive: Expert-Augmented Streaming Analytics System for Emergency Services and Humanitarian Organizations, *2018 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM)*.

Poblet, M., García-Cuesta, E., and Casanovas, P. (2017) Crowdsourcing roles, methods and tools for data-intensive disaster management, *Information Systems Frontiers*, *20*, 6, 1363–1379.

Purohit, H., Castillo, C., Diaz, F., Sheth, A., and Meier, P. (2013) Emergency-relief coordination on social media: Automatically matching resource requests and offers, *First Monday*, *19*, 1.

Purohit, H., Hampton, A., Bhatt, S., Shalin, V. L., Sheth, A. P., and Flach, J. M. (2014) Identifying Seekers and Suppliers in Social Media Communities to Support Crisis Coordination, *Computer Supported Cooperative Work (CSCW)*, *23*, 4-6, 513–545.

Reuter, C., and Spielhofer, T. (2017) Towards social resilience: A quantitative and qualitative survey on citizens' perception of social media in emergencies in Europe, *Technological Forecasting and Social Change*, *121*, 168–180.

Rogstadius, J., Vukovic, M., Teixeira, C. A., Kostakos, V., Karapanos, E., and Laredo, J. A. (2013) CrisisTracker: Crowdsourced social media curation for disaster awareness, *IBM Journal of Research and Development*, *57*, 5.

Sánchez de Miguel, A., Gomez Castaño, J., Lombraña, D., Zamorano, J., & Gallego, J. (2015) Cities at night: citizens science to rescue an archive for the science, *IAU General Assembly,* 22.

Sheth, A., Jadhav, A., Kapanipathi, P., Lu, C., Purohit, H., Smith, G. A., and Wang, W. (2014) Twitris: A system for collective social intelligence, *Encyclopedia of social network analysis and mining,* 2240–2253.

Starbird, K., Muzny, G., and Palen, L. (2012) Learning from the crowd: collaborative filtering techniques for identifying on-the-ground Twitterers during mass disruptions, *Proceedings of 9th International Conference on Information Systems for Crisis Response and Management, ISCRAM*, 1–10.

S&T FRG Using Social Media Enhanced Situational Awareness Decision Support. (2014) *Department of Homeland Security*, https://www.dhs.gov/publication/using-social-media-enhanced-situational-awareness-decision-support

Tapia, A. H., Bajpai, K., Jansen, B. J., Yen, J., & Giles, L. (2011) Seeking the trustworthy tweet: Can microblogged data fit the information needs of disaster response and humanitarian relief organizations, *Proceedings of 8th International Conference on Information Systems for Crisis Response and Management, ISCRAM*, 1–10.

Witten, I. H., Frank, E., Hall, M. A., & Pal, C. J. (2016) Data Mining: Practical machine learning tools and techniques, *Morgan Kaufmann.*

Evaluation Framework for the iTRACK Integrated System

Ahmed A. Abdelgawad
Centre for Integrated Emergency Research,
University of Agder, Norway
ahmedg@uia.no

Tina Comes
Faculty Technology, Policy & Management,
TU Delft, Netherlands /
Centre for Integrated Emergency Research,
University of Agder, Norway
tina.comes@uia.no

ABSTRACT

Evaluation and testing are major steps in the development of any information system, particularly if it is to be used in high-risk contexts such as conflicts. While thus far there are various approaches for testing against technology requirements; usability or usefulness, there is a lack of a comprehensive evaluation framework that combines the three elements. The lack of such a framework and commonly agreed standards constitutes a barrier for innovation, and at the same time imposes risks to responders if the technology is introduced without proper testing. This paper aims to close this gap. Based on a reviewing of evaluation methods and measurement metrics, we design a comprehensive evaluation framework including common code quality testing metrics, usability testing methods, subjective usefulness questionnaires, and performance indicators. We demonstrate our approach by using the example of an integrated system for the safety and security of humanitarian missions, and we highlight how our approach allows measuring the system's quality and usefulness.

KEYWORDS

Evaluation Framework, Software Testing, Software Usability, Software Usefulness, Humanitarian Disaster.

INTRODUCTION

Those who try to provide aid to the most vulnerable populations in the Middle East are increasingly risking their own lives and safety. According to the Aid Worker Security Database (Humanitarian Outcomes 2019), the number of humanitarian workers that fall victim to attacks continues to rise. Organizations in the field are confronted with mounting tensions as they seek to maintain access to populations in need. Thus, there is a new role for technology to support operations. Yet, these innovations and particularly the use of ICT in conflict can cause severe risks, ranging from privacy violations to threatening the lives and safety of those it is designed to protect.

Evaluation and testing is a major step in the development life-cycle of any software system, and it is a vital phase in quality assurance of the system (Jovanović 2006). Software system evaluation frameworks aim at assessing the system quality and sophistication from diverse viewpoints (Boloix and Robillard 1995). Nonetheless, there is no comprehensive evaluation framework that combines technology, functionality and usefulness tests for humanitarian conflict disasters. Such a test requires that the standards and problems of humanitarian innovation and experimentation are met (Sandvik et al. 2017) and the context of the problem is considered. In conflicts, a major challenge is dealing with sensitive information and organizational barriers to information sharing (Van de Walle and Comes 2015) and to evaluate risks as they emerge (Van de Walle and Comes 2014). The lack of such a framework and commonly agreed standards constitutes a major barrier for innovation, and at the same time may impose risks to responders if the technology is introduced without proper testing.

The goal of this paper is to compile a comprehensive evaluation framework for integrated systems in humanitarian conflicts, based on a review of evaluation standards and metrics. The framework should assist in measuring the **quality** and **usefulness** of a system, from the individual components' performance to the overall system. Software system **quality** is defined by the Institute of Electrical and Electronics Engineers IEEE as "the degree to which a system, component, or process meets specified requirements" and "the degree to which a system, component, or process meets customer or user needs or expectations" (IEEE Computer Society 1991). The International Software

Testing Qualifications Board ISTQB defines the quality in general as "the degree to which a component, system or process meets specified requirements and/or user/customer needs and expectations" ("ISTQB Glossary" 2015), whereas it defines the software quality as "the totality of functionality and features of a software product that bear on its ability to satisfy stated or implied needs" ("ISTQB Glossary" 2015). In total, the **quality** of software is about meeting the **specified requirements** as well as **user satisfaction**. The former is achieved via testing the software system components individually or together, or the whole system against the requirements in terms of specifications, use cases, design documents, etc., while the latter is achieved via testing the system **usability** and **user-satisfaction** (Nielsen 1993).

System **usefulness** means that "a product, website or application should solve a problem, fill a need or offer something people find useful" (Sauro 2011). Based on Fred Davis' usefulness construct, system usefulness is about helping users in accomplishing job tasks quicker, improving job performance, productivity, and effectiveness, in addition to making the job easier to do in general. Figure 1 shows the pillars of our suggested integrated system evaluation framework.

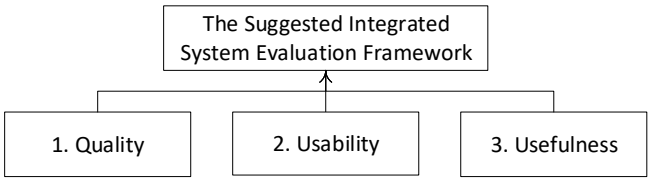


Figure 1. Suggested Integrated System Framework

The rest of this paper is organized as follows: the next section provides an overview of our methodology. The 'Results' section describes the evaluation methods reviewed and the evaluation methods selected for OUR case study in the context of the EU H2020 project iTRACK (https://www.itrack-project.eu). We conclude with a 'Summary' section.

METHODOLOGY

To achieve the goal of this paper, we surveyed relevant sources for "software testing methods" and "technology usefulness instruments" to collect quality and the usefulness assessment methods and metrics. Websites of organizations connected to humanitarian conflicts were the target of our initial investigation, such as Aid in Danger, the European Interagency Security Forum EISF, the United Nations Development Program UNDP, etc. We used a variety of keywords like: "software testing", "software evaluation", "information system testing", "information system evaluation", "software quality", "information system quality", sometimes even just using "software" and searched for relevant material in results. This search was not fruitful. To mitigate the situation, we have used the same search keywords mentioned above and broadened our search circle to include sources like:

- International Organization for Standardization ISO (https://www.iso.org/publication-list.html),
- International Electrotechnical Commission IEC (http://www.iec.ch),
- IEEE (https://www.ieee.org),
- ISTQB (https://www.istqb.org),
- Scientific publications (via Google Scholar and others), and
- Other material available on the Internet in general.

The results of this investigation were organized under the three pillars of our intended framework: quality, usability, and usefulness.

RESULTS

The quality of software, as indicated previously, is about meeting the specified requirements as well as user satisfaction. The former is achieved by testing the software system components individually or together, and the whole system against the requirements in terms of specifications, use cases, design documents, etc. The latter is achieved via testing the system usability and user-satisfaction directly with users and subjectively via questionnaires administered to them. System usefulness can be measured in terms performance indicators of an individual, a team, or an organization as a result of using the system, as well as subjectively by explicitly asking the users to provide their opinions on the usefulness of the system.

Our literature survey results were compiled under the first two main subsections of this section: 'Software Testing and Quality', and 'Software Usability'. Each of these subsections was concluded by our selected methods and metrics for the iTRACK system. The third main subsection focuses on the usefulness of the iTRACK system.

SOFTWARE TESTING AND QUALITY

SOFTWARE TESTING METHODS

All software testing methods are classified under either Black-Box, White-Box, or in-between i.e. Grey-Box (Jovanović 2006). The software testing method will be decided based on the testers access to the internal structure of the software system under test (its source code): (1) **Black-Box Testing Method** (aka. Specifications-Based, or Behavioral testing) is a software testing method in which no need to access the source code of the tested item. ("Black Box Testing" 2017). (2) **White-Box Testing Method** (aka. Clear-Box, Glass-Box, Transparent-Box, Open-Box, Code-Based testing, or Structural testing) is a software testing method to test a software item with knowledge of its internal structure, design, and implementation (source code) ("What is a White Box Testing?" 2012; "White Box Testing" 2010). (3) **Grey-Box Testing Method** is a combination of the Black-Box and White-Box software testing methods ("Gray Box Testing" 2010).

SOFTWARE TESTING LEVELS

Software testing is being conducted on four different levels: Unit, Integration, Functional, and Acceptance.

Unit Testing Level (aka. Component, Module, Program, or Structural testing)[1] ("Types of Software Testing for Dummies" 2013) is a typical Whit-Box method testing level. "Unit testing is micro testing which is done by developers to ensure that each and every individual unit of source code performing well enough to match their expectation" (Müller et al. 2011; "Types of Software Testing for Dummies" 2013). This testing level is all about answering the question of "**Did we build it right?**".

Integration Testing Level aims at examining how units/components/parts of the system work together. The different units/components are tested working together to ensure that interfaces and interactions among them or other parts of the system (e.g., operating system, file system, hardware) are performing well and in compliance with the requirements/specifications (Müller et al. 2011; "Types of Software Testing for Dummies" 2013).

System Testing Level is a system testing that is concerned with the complete functionality and behavior of the whole system (Müller et al. 2011). The environment where this testing level is conducted should resemble the production environment to reduce the environment-specific failures (Müller et al. 2011). System testing level "may include tests based on risks and/or on requirements specifications, business processes, use cases, or other high level text descriptions or models of system behaviour, interactions with the operating system, and system resources" (Müller et al. 2011). This testing level inspects both functional and non-functional requirements and could be conducted by an independent tester (Müller et al. 2011).

Figure 2 shows the relationship between the testing methods and the testing levels.

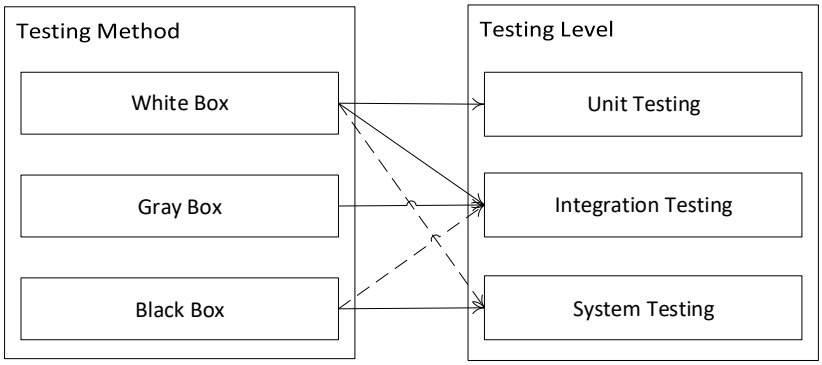


Figure 2: Testing Levels and Methods

[1] A structural or an architectural testing aims at knowing what is happening inside the system.

THE ITRACK SOFTWARE TESTING AND QUALITY ASSURANCE

Unit testing has been performed using the tools in the iTRACK development environment. The requirements for the tests were developed in a series of interviews, field research and simulation tests (Noori et al. 2017). Full documentation is available on the project website https://www.itrack-project.eu. Successive versions of the iTRACK corresponding deliverables have reported the resulted testing metrics. One of the metrics reported is the Code Coverage which is "an analysis method that determines which parts of the software have been executed (covered) by the test suite and which parts have not been executed, e.g., statement coverage, decision coverage or condition coverage." (Judy McKay et al. 2016).

In the iTRACK development environment, an Integration testing for mainly the server-side components was carried out. In a simulation exercise in April 2018, another Integration testing including the client-side components was performed in addition to a System level testing to evaluate end-to-end workflows.[2] Before the final deployment, another System-level testing is planned. After deployment other metrics like the numbers and rates of bugs and issues reported, fixes; enhancements; improvements and new features released, issues reopened, etc.(for others, please check (Data 2017; "Issues" 2018)) can be used to indicate the quality of the iTRACK system.

SOFTWARE USABILITY

Usability Testing Level (aka. Acceptance Testing) is the final testing phase prior to sending the software to the production environment in the market. This level aims at answering the question of "**did we build the right thing?**". The testing is conducted firstly in the developers' workplace by the internal developers, testers, or users employed for that reason, which is called in general Alpha testing. Then the testing is conducted at the users' place by the users to provide feedback before the system release to the market, which is called Beta testing (Müller et al. 2011; "Types of Software Testing for Dummies" 2013). "The goal in acceptance testing is to establish confidence in the system, parts of the system or specific non-functional characteristics of the system. Finding defects is not the main focus in acceptance testing" (Müller et al. 2011).

Acceptance in terms of usability is defined as "a quality attribute that assesses how easy user interfaces are to use. The word 'usability' also refers to methods for improving ease-of-use during the design process" (Nielsen 2012). Usability can be measured objectively and subjectively. Objectively by asking users to complete certain tasks and observe them. Subjectively by asking users to fill questionnaires about the usability of the software system.

USABILITY TESTING SESSIONS

Usability testing aims at observing users using the tested software under test. A set of users, preferably similar in characteristics to the end-users, should be employed and asked to fulfill goal-based tasks using the software; during these testing sessions usability problems would be observed (Corona 2014). Observations are in terms of how users use the software. Then the developers will be able to know the correct needed features and understand the issues facing the users while using the software. Accordingly, developers can make improvements based on these observations.

USABILITY EVALUATION (TESTING METRICS)

As mentioned above, the users will be given a set of tasks to complete during the testing session. The following metrics could be calculated:

- Learnability:

How easy it is for the user to learn using the system (EN_Tech_Direct 2012; Nielsen 2012). Learnability could be measured by:

$$Learnability = \frac{T_2 - T_1}{T_1}$$

Where T_1 and T_2 are the durations taken by the user to accomplish the same task for the first and the second times respectively.

[2] For a full documentation of the test results, see: https://www.itrack-project.eu/media/articles/files/iTRACK_D7.3%20–%20Results%20of%20integrated%20system%20evaluation.pdf

- Efficiency:

How quickly it is for the user to accomplish tasks after learning the system (EN_Tech_Direct 2012; Nielsen 2012). Efficiency could be measured by finding the total time saved between the first and the last times doing a certain task.

- Effectiveness:

How well the user achieves her/his goals using the system (EN_Tech_Direct 2012). Effectiveness could be measured by classifying the accomplishment level of the tasks by different users (in terms of **S** for Success, **F** for Failure or **P** for Partial **S**uccess).

e.g.:

	Task 1	**Task 2**	**Task 3**	**…**	**Task N**
User 1	F	S	S		PS
User 2	S	S	F		F
…					
User M	F	S	PS		F

- Completion Rates:

"Often called the fundamental usability metric or the gateway metric, completion rates are a simple measure of usability. It's typically recorded as a binary metric (in terms of **1** for Task Success and **0** for Task failure). If users cannot accomplish their goals, not much else matters" (Sauro 2011).

e.g.:

	Task 1	**Task 2**	**Task 3**	**…**	**Task N**
User 1	1	0	1		1
User 2	0	1	0		1
…					
User M	1	1	1		0

- Usability Problems:

This measure is about user interface problems which the users encounter during the test. The moderator/observer should "describe the problem and note both **how many** and **which users encountered it**. Knowing the probability, a user will encounter a problem at each phase of development can become a key metric for measuring usability activity impact and [return on investment] ROI. Knowing which user encountered it allows to better predict sample sizes, problem discovery rates and what problems are found by only a single user" (Sauro 2011).

Observer notes should be based on the **frequency** of the usability problem: "Is it common or rare?", the **impact** of the problem: "Will it be easy or difficult for the users to overcome?", and the **persistence** of the problem: "Is it a one-time problem that users can overcome once they know about it or will users repeatedly be bothered by the problem?" (Nielsen 1994).

- Errors:

"Record any unintended action, slip, mistake or omission a user makes while attempting a task. Record each instance of an error along with a description. For example, 'user entered last name in the first name field'" (Sauro 2011). Afterward, the moderator/observer can add severity ratings to the errors, otherwise, categorize these errors. "Errors provide excellent diagnostic information and, if possible, should be mapped to [user interface] problems. Errors are somewhat time-consuming to collect, as they usually require a moderator or someone to review recordings" (Sauro 2011). Errors are detected via the observer's notes, for example, "user entered last name in the first name field" (Sauro 2011).

- Task Time:

"**Total task duration** is the de facto measure of efficiency and productivity. Record how long it takes a user to complete a task in seconds and or minutes. **Start task times when users finish reading task scenarios and end the time when users have finished all actions** (including reviewing)" (Sauro 2011).

	Task 1	**Task 2**	**Task 3**	**…**	**Task N**
User 1	00:05:30	00:14:30	00:05:30		00:01:30
User 2	00:04:25	00:13:20	00:04:25		00:01:20
…					
User M	00:06:45	00:12:15	00:06:45		00:02:15

- Page Views/Clicks:

"For websites and web-applications, these fundamental tracking metrics might be the only thing you have access to without conducting your own studies. Clicks have been shown to correlate highly with time-on-task which is probably a better measure of efficiency. The first click can be highly indicative of a task success or failure" (Sauro 2011). Page Views/Clicks could be detected by counting the clicks and page views by the system itself.

- Expectation:

"Users have an expectation about how difficult a task should be based on subtle cues in the task-scenario. Asking users how difficult they expect a task to be and comparing it to actual task difficulty ratings (from the same or different users) can be useful in diagnosing problem areas" (Sauro 2011).

Pre-task		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
How difficult you think Task M will be?	Very easy	○	○	○	○	○	○	○	Very difficult
- Please explain your choice:									

- Task Level Satisfaction:

"After users attempt a task, have them answer a few or just a single question about how difficult the task was. Task level satisfaction metrics will immediately flag a difficult task, especially when compared to a database of other tasks" (Sauro 2011). For example, was "Task M" easy to do?

Post task		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
How difficult did you find Task M?	Very easy	○	○	○	○	○	○	○	Very difficult
• Please explain your choice:									

- Single Usability Metric (SUM):

"There are times when it is easier to describe the usability of a system or task by combining metrics into a single score, for example, when comparing competing products or reporting on corporate dashboards. SUM is a standardized average of measures of effectiveness, efficiency of satisfaction and is typically composed of 3 metrics: **completion rates**, **task-level satisfaction** and **task time**" (Sauro 2011).

USABILITY AND USER EXPERIENCE SUBJECTIVE EVALUATION

Over the last 30 years, several usability and user-experience subjective questionnaires have been used to assess the usability aspects as well as reliability and validity of software systems. EduTech Wiki collected many of these questionnaires. They can be used for all systems including websites and mobile apps ("Usability and user experience surveys" 2016).

According to Perlman: "Questionnaires have long been used to evaluate user interfaces … Questionnaires have also long been used in electronic form … For a handful of questionnaires specifically designed to assess aspects of usability, the validity and/or reliability have been established …" (Perlman 2015). In the following table, we enlist some of the subjective questionnaires resulted from our review.

Questionnaire title	Questionnaire type	Number of items	Sub-scales/Construct	Reference
Perceived Usefulness and Ease of Use	7-points scale	12	○ Perceived usefulness, and ○ Perceived ease of use.	(Davis 1989)
Software Usability Scale (SUS)	5-points scale	10	○ Usability and ○ Learnability.	(Borsci et al. 2009; Brooke 1996; Sauro 2015; "System usability scale" 2017)
Standardized User Experience Percentile Rank Questionnaire (SUPR-Q)	11-points scale	8	○ Usability, ○ Trust, ○ Appearance, and ○ Loyalty.	(Sauro 2015)
User Experience	7-points scale	26	○ Attractiveness,	(Laugwitz et al. 2006,

Questionnaire title	Questionnaire type	Number of items	Sub-scales/Construct	Reference
Questionnaire (UEQ)			○ Perspicuity, ○ Efficiency, ○ Dependability, ○ Stimulation, and ○ Novelty.	2008)

THE ITRACK USABILITY AND USER EXPERIENCE TESTING

The iTRACK system consists of several packages that have different roles in supporting humanitarian aid workers. Based on these roles a list of usability tasks was prepared. This list compiles the possible iTRACK system features to be tested per iTRACK system component. Each feature to be tested is supplied with a description of its test. The idea, in general, is to find if the participants will be able to fulfill the required tasks with success, partial success, or failure. One of the iTRACK system features is the "threat creation", which as the name implies, enables users to create a threat report so that other iTRACK system users can be careful. One example of a test activity description for this feature is: "create threats on the map, indicate e.g. threat types, estimated impact, etc."
The metrics mentioned previously in the review will be used whenever suitable to find our usability issues. For our select usability task example, before doing this task, the participants should answer the following question:

Before Task

How difficult you think this task will be?	Very easy	○	○	○	○	○	○	○ Very difficult
- Please explain your choice:								

After finishing the task, the participants should log the time they took to complete this task and report if the result was success, partial success, or failure. Then answer a question like the one they have answered before the task:

After Task

Task								Log
Task Time								__:__:__
Completion (Success, **F**ailure and **P**artial **S**uccess**)**								○ S ○ PS ○ F
How difficult did you find this task?	Very easy	○	○	○	○	○	○	○ Very difficult
- Please explain your choice:								

These ***Before*** and ***After Task*** questions will enable calculating most of the usability metrics mentioned in the "Usability Evaluation (Testing Metrics)" subsection of this paper.

As indicated in the review, many questionnaires could be used to subjectively measure different constructs. Usually, users' time is limited and filled with several activities. To use this limited time efficiently, our team has selected only Davis' Perceived Usefulness and Ease of Use questionnaire, and UEQ questionnaires to be administered to the users as subjective usability measures. Davis' Perceived Usefulness and Ease of Use questionnaire is short and assesses the usefulness in addition to the ease-of-use, while UEQ gives more insights into the experience of the user. These questionnaires are to be administered to users for each of the iTRACK system components individually so that users can understand the text of questionnaires within the context of each of these components.

- iTRACK Perceived Usefulness and Ease of Use

Instructions:

- Try to respond to all the items.
- For items that are not applicable, use: NA
- Add a comment about an item if needed

Perceived usefulness			**1**	**2**	**3**	**4**	**5**	**6**	**7**		**NA**
1.	Using the iTRACK system in my job would enable me to accomplish tasks more quickly	Unlikely	○	○	○	○	○	○	○	Likely	○
2.	Using the iTRACK system would improve my job performance	Unlikely	○	○	○	○	○	○	○	Likely	○
3.	Using the iTRACK system in my job would increase my productivity	Unlikely	○	○	○	○	○	○	○	Likely	○
4.	Using the iTRACK system would enhance my effectiveness on the job	Unlikely	○	○	○	○	○	○	○	Likely	○
5.	Using the iTRACK system would make it easier to do my job	Unlikely	○	○	○	○	○	○	○	Likely	○
6.	I would find the iTRACK system useful in my job	Unlikely	○	○	○	○	○	○	○	Likely	○
Perceived ease of use			**1**	**2**	**3**	**4**	**5**	**6**	**7**		**NA**
7.	Learning to operate the iTRACK system would be easy for me	Unlikely	○	○	○	○	○	○	○	Likely	○
8.	I would find it easy to get the iTRACK system to do what I want it to do	Unlikely	○	○	○	○	○	○	○	Likely	○
9.	My interaction with the iTRACK system would be clear and understandable	Unlikely	○	○	○	○	○	○	○	Likely	○
10.	I would find the iTRACK system to be flexible to interact with	Unlikely	○	○	○	○	○	○	○	Likely	○
11.	It would be easy for me to become skilful at using the iTRACK system	Unlikely	○	○	○	○	○	○	○	Likely	○
12.	I would find the iTRACK system easy to use	Unlikely	○	○	○	○	○	○	○	Likely	○

- iTRACK UEQ

Instructions: For each of the following items, mark one box that best describes the iTRACK system.

		1	**2**	**3**	**4**	**5**	**6**	**7**	
1.	annoying	○	○	○	○	○	○	○	enjoyable
2.	not understandable	○	○	○	○	○	○	○	understandable
3.	creative	○	○	○	○	○	○	○	dull
4.	easy to learn	○	○	○	○	○	○	○	difficult to learn
5.	valuable	○	○	○	○	○	○	○	inferior
6.	boring	○	○	○	○	○	○	○	exciting
7.	not interesting	○	○	○	○	○	○	○	interesting
8.	unpredictable	○	○	○	○	○	○	○	predictable
9.	fast	○	○	○	○	○	○	○	slow
10.	inventive	○	○	○	○	○	○	○	conventional
11.	obstructive	○	○	○	○	○	○	○	supportive
12.	good	○	○	○	○	○	○	○	bad
13.	complicated	○	○	○	○	○	○	○	easy
14.	unlikable	○	○	○	○	○	○	○	pleasing
15.	usual	○	○	○	○	○	○	○	leading edge
16.	unpleasant	○	○	○	○	○	○	○	pleasant
17.	secure	○	○	○	○	○	○	○	not secure
18.	motivating	○	○	○	○	○	○	○	demotivating
19.	meets expectations	○	○	○	○	○	○	○	does not meet expectations
20.	inefficient	○	○	○	○	○	○	○	efficient
21.	clear	○	○	○	○	○	○	○	confusing
22.	impractical	○	○	○	○	○	○	○	practical
23.	organized	○	○	○	○	○	○	○	cluttered
24.	attractive	○	○	○	○	○	○	○	unattractive
25.	friendly	○	○	○	○	○	○	○	unfriendly
26.	conservative	○	○	○	○	○	○	○	innovative

THE ITRACK SYSTEM USEFULNESS

System usefulness is about how the system is helping users in accomplishing their job tasks quicker, improving their job performance, productivity, effectiveness, and in general making doing their job easier, in other words, the enhancement in performance of the users doing their jobs as a result of using the system (Davis 1993). Davis found that in predicting the actual system use, system usefulness is 1.5 times more important than ease of use or usability (Davis 1993; Sauro 2011).

The iTRACK system aims to improve the security and efficiency of civilian humanitarian missions. Using the iTRACK system is expected to enhance the performance of its users. In the following subsections, we will describe the metrics that we think would be useful in assessing the performance of the iTRACK system components, the usage of these components, in addition to the performance of the individuals, teams and overall organization because of using the iTRACK system.

A humanitarian mission could be divided into three phases: 1. Planning, 2. Executing, and 3. Response and Recovery. Each of these phases has different tasks according to the mission on one hand, and the threat/attack this mission is facing on the other hand. These tasks are performed by individuals who could be part of one team or gathered from different teams. Accordingly, an indicator could be on the highest resolution scale i.e. measuring the performance of an individual working on one task. It could be scaled up to the case in which this individual is working through a full phase or a whole mission as well. The same principle applies when the indicator is scaled up from an individual to a team or an organization. Figure 3 shows indicator measurement levels granularity that we have used while composing the performance indicators in the following subsections.

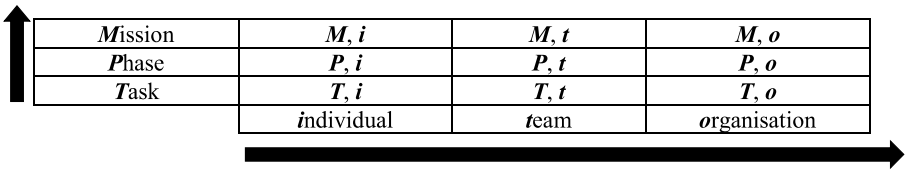


Figure 3: Indicator Measurement Levels Granularity (Arrows Go towards Higher Levels of Aggregations)

USAGE INDICATOR OF THE ITRACK SYSTEM

- Individual Usage per System Component

Usage Indicator ui_i: how many times an individual uses (open to look for or check anything) one of the iTRACK system components per time unit, therefore ui_i is measured in [times/hour].

- Team Average Usage per System Component

Usage Indicator ui_t: the average number of times of all individuals who belong to a team t use one of the iTRACK system components per time unit:

$$ui_t = \frac{\sum_{i \in t} ui_i}{|t|}$$

ui_t is measured in [times/hour], where $|t|$ is the number of all individuals who belong to the team t.

- Organization Average Usage per System Component

Usage Indicator ui_o: the average number of times of all individuals who belong to an organization o use one of the iTRACK system components per time unit:

$$ui_o = \frac{\sum_{i \in o} ui_i}{|o|}$$

ui_o is measured in [times/hour], where $|o|$ is the number of all individuals who belong to the organization o.

COORDINATION INDICATOR USING THE ITRACK SYSTEM

- Reaction Time to Messages

The iTRACK system provides users with the ability to exchange text messages. The value of this indicator is based on how long it takes a user to react because of a message she/he has received on the average. Indicators, like replying to the message or performing an action because of the message content, could be insightful. Yet, aside from being hard to measure, there are cases where a message does not need a reply or an action to be performed. For simplicity, reaction to a message could be considered as opening or reading this message (marking

it as read). For example, during the first task of the planning phase PT_1, the time passed between receiving certain message x by an individual until reading it is $\mathrm{rmt}_x^{\mathrm{PT}_1}$. Accordingly:

- For an individual, the total reaction time to all messages during this task is $\mathrm{rmt}_{total}^{\mathrm{PT}_1} = \sum_{x\in \mathrm{PT}_1} \mathrm{rmt}_x^{\mathrm{PT}_1}$ and the average is $\mathrm{rmt}_{average}^{\mathrm{PT}_1} = \frac{\sum_{x\in \mathrm{PT}_1} \mathrm{rmt}_x^{\mathrm{PT}_1}}{|\{x: x\in \mathrm{PT}_1\}|}$.
- For an individual, the total reaction time to all messages during all tasks of the whole planning phase is $\mathrm{rmt}_{total}^{P} = \sum_{x\in P} \mathrm{rmt}_x^{P}$ and the average is $\mathrm{rmt}_{average}^{P} = \frac{\sum_{x\in P} \mathrm{rmt}_x^{P}}{|\{x: x\in P\}|}$. Similarly, rmt_{total}^{E} and $\mathrm{rmt}_{average}^{E}$, and rmt_{total}^{R} and $\mathrm{rmt}_{average}^{R}$ can be calculated.
- For an individual, the total reaction time to all messages during the whole mission is $\mathrm{rmt}_{total}^{mission} = \sum_{x\in M} \mathrm{rmt}_x^{M}$ or $\mathrm{rmt}_{total}^{P} + \mathrm{rmt}_{total}^{E} + \mathrm{rmt}_{total}^{R}$, and the average is $\mathrm{rmt}_{average}^{mission} = \frac{\sum_{x\in M} \mathrm{rmt}_x^{M}}{|\{x: x\in M\}|}$.

In case the indicator is to be calculated for a team or an organization, the value can be calculated as the average of averages of all individuals who belong to that team or that organization respectively.

TIME-SAVING USING THE ITRACK SYSTEM

This indicator requires two different entities (two individuals, two teams, or two organizations) executing the same task, one of these entities uses the iTRACK system, while the other does not. Otherwise, a comparison can be conducted between the performance of the same entity in the current time and the last time this entity performed the same task, phase, or mission to measure the **learnability**. A comparison can be also conducted between the performance of the entity in the current time and the first time this entity performed the same task, phase, or mission to measure the **efficiency** (this answers questions like: how are we doing compared to the first time we have used the iTRACK system? and what is our overall trend using the iTRACK system?).

- Individual Time Saving Indicator

Let $\mathrm{ts}_i^{\mathrm{PT}_1}$ denotes the individual's time saved per task PT_1. Therefore, $\mathrm{ts}_i^{\mathrm{PT}_1}$ is the difference between the time elapsed by an individual (using the iTRACK) and the time elapsed by another individual (not using the iTRACK) –otherwise the past reading of the time elapsed by the same first individual– executing the same task PT_1. Accordingly, the individual's time saved for all tasks during the whole planning phase is $\mathrm{ts}_i^{P} = \sum_{x\in P} \mathrm{ts}_i^{x}$, similarly, we can calculate the individual's time saved during the execution phase ts_i^{E}, and the individual's time saved during the response and recovery phase ts_i^{R}. Furthermore, the individual's time saved during the whole mission is $\mathrm{ts}_i^{M} = \mathrm{ts}_i^{P} + \mathrm{ts}_i^{E} + \mathrm{ts}_i^{R}$.

- Team Average Time Saving Indicator

For the task PT_1, the average time saved across individuals who belong to a team t performing this task is $\frac{\sum_{i\in t} \mathrm{ts}_i^{\mathrm{PT}_1}}{|t|}$. The same equation can be applied for a phase (e.g. P) and a whole mission, i.e. $\frac{\sum_{i\in t} \mathrm{ts}_i^{P}}{|t|}$, and $\frac{\sum_{i\in t} \mathrm{ts}_i^{M}}{|t|}$ respectively.

- Organization Overall Average Time Saving Indicator

For an organization o, the average time saved across all individuals who belong to this organization during the task PT_1, the phase P (for example), or the whole mission can be calculated by $\frac{\sum_{i\in o} \mathrm{ts}_i^{\mathrm{PT}_1}}{|o|}$, $\frac{\sum_{i\in o} \mathrm{ts}_i^{P}}{|o|}$, and $\frac{\sum_{i\in o} \mathrm{ts}_i^{M}}{|o|}$ respectively.

In general, the time saving that is related to specific tasks like loading trucks, completing deliveries, etc. can be separately considered as independent indicators on their own.

COST-SAVING USING THE ITRACK SYSTEM

Cost could be calculated as the real cost of executing the task(s), phase(s), or mission(s) per an individual, team, or organization, which is difficult to be done quickly. Otherwise, it can be taken as the average cost per the time unit for an individual during executing task(s), phase(s), or mission(s) multiplied by her/his time elapsed executing this/these task(s), phase(s), or mission(s) respectively. The same approach can be applied to a team or an organization, by summing the cost of the individuals who belong to this team or organization respectively.

Like the time-saving indicator, this indicator requires two entities (individual/team/organization) executing the same task for comparison, one entity uses the iTRACK system, while the other does not. Otherwise, the comparisons can be conducted between the performance of the entity in the current time and the last time the

entity performed the same task, phase, or mission to measure the **learnability**. The comparisons can be also conducted between the performance of the entity in the current time and the first time this entity performed the same task, phase, or mission to measure the **efficiency**. Like the time-saving indicators, cost saving for tasks related to specific tasks like loading trucks, completing deliveries, etc. can be separately considered as independent indicators on their own.

THE ITRACK USEFULNESS SUBJECTIVE EVALUATION

Several questionnaires can subjectively assess the usefulness of the system from the users' viewpoint. For example, from the reviewed questionnaires that cover usefulness in the "Usability and User Experience Subjective Evaluation" subsection of this paper:

- Davis' Perceived Usefulness and Ease of Use,
- CSUQ/PSSUQ, and
- USE.

To subjectively measure the usefulness of the iTRACK system or one its components, as mentioned earlier, Davis' Perceived Usefulness and Ease of Use questionnaire could be used, as it has been very well accepted and used for a long time (as it is part of the Technology Acceptance Model TAM) (Müller et al. 2011). Taking into consideration the limited time of the users testing the iTRACK system, another reason to select Davis' is that it is shorter than the others.

SUMMARY

Evaluation and testing are major steps in the development of any software, but they are of particular importance if innovation is to be used in highly sensitive contexts such as humanitarian conflicts. It is a vital phase in quality assurance of the system in terms of assessing the system quality and sophistication from diverse viewpoints. Nonetheless, a comprehensive evaluation framework that combines technology, functionality and usefulness tests does not exist. The paper developed metrics that helps in measuring the quality and usefulness by using the case of the iTRACK system, a tracking and monitoring system for humanitarian conflicts.

This paper reviewed the adequate evaluation methods and measurement metrics, to compile this comprehensive evaluation framework to assist in measuring the quality and usefulness of the iTRACK system. We have indicated that the software system quality is assessed in terms of software testing. We have introduced different software testing methods and levels that are used in software testing in general. The usability of the iTRACK system is assessed separately, either via the system usability testing directly with users or via questionnaires administered to them. Moreover, for users to find the system useful, the system should solve a problem they are facing, or fill a need or offer them something. System usefulness is about helping in accomplishing job tasks quicker, improving job performance, productivity, and effectiveness, in addition to making it easier to do the job. To measure the usefulness of the iTRACK system, we have suggested several performance indicators, as well as by subjectively recognizing the users' opinion about the usefulness of the system. Figure 4 shows the pillars and details of the suggested integrated system evaluation framework.

Finally, the iTRACK integrated system evaluation framework has been reviewed by several iTRACK project partners that belong to academia, and software development and their notes were taken into consideration in the final version.

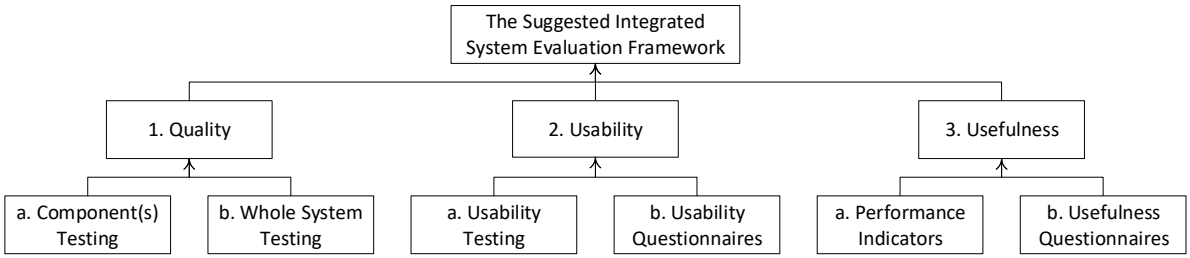


Figure 4. The Detailed Suggested Integrated System Framework

The iTRACK project conducted a simulated environment exercise in April 2018. This exercise is an example of applying the iTRACK integrated system evaluation framework, as it was the first iTRACK system testing with users. During this exercise, a set of participants tested the ready iTRACK system components. The participants were asked to complete certain tasks using the iTRACK system. The suitable usability and usefulness metrics and

questionnaires suggested in this paper were used during the exercise. As a final note, an independent reporting and evaluation software system applying these metrics for the iTRACK is under development.

ACKNOWLEDGMENTS

This work is carried out as part of the iTRACK project, funded by the European Union's Horizon 2020 research and innovation Program under grant agreement No 700510.

REFERENCES

Corona, A. (2014). "What is Usability and Why Should I Care?" *Yale Digital Conference*, <https://digitalconference.yale.edu/what-usability-and-why-should-i-care> (Feb. 14, 2019).

Humanitarian Outcomes. (2019). "Aid Worker Security Database." <https://aidworkersecurity.org/> (Feb. 14, 2019).

"Black Box Testing." (2017). *Software Testing Fundamentals*, <http://softwaretestingfundamentals.com/black-box-testing/> (Mar. 16, 2018).

Boloix, G., and Robillard, P. N. (1995). "A software system evaluation framework." *Computer*, 28(12), 17–26.

Borsci, S., Federici, S., and Lauriola, M. (2009). "On the dimensionality of the System Usability Scale: a test of alternative measurement models." *Cognitive Processing*, 10(3), 193–197.

Brooke, J. (1996). "SUS-A quick and dirty usability scale." *Usability evaluation in industry*, 189(194), 4–7.

Data, N. (2017). "13 Essential Software Development Metrics to Ensure Quality." *The School of Little Data*, <https://blog.usenotion.com/13-essential-software-development-metrics-to-ensure-quality-219cfc264ed1> (Nov. 19, 2018).

Davis, F. D. (1989). "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology." *MIS Quarterly*, 13(3), 319–340.

Davis, F. D. (1993). "User acceptance of information technology: system characteristics, user perceptions and behavioral impacts." *International Journal of Man-Machine Studies*, 38(3), 475–487.

EN_Tech_Direct. (2012). "Usability Test Report for Mobile Applications Part II: When the Perfect Combination of Smart Phone & Music Application." *Technical Direct*, <http://www.technical-direct.com/en/usability-test-report-for-mobile-applications-part-ii-when-the-perfect-combination-of-smart-phone-music-application/> (Feb. 19, 2018).

"Gray Box Testing." (2010). *Software Testing Fundamentals*, <http://softwaretestingfundamentals.com/gray-box-testing/> (Mar. 17, 2018).

IEEE Computer Society (Ed.). (1991). *IEEE standard glossary of software engineering terminology*. Institute of Electrical and Electronics Engineers, New York.

"Issues." (2018). *GitLab*, <https://docs.gitlab.com/11.6/ee/user/project/issues/index.html> (Nov. 19, 2018).

"ISTQB Glossary." (2015). *ISTQB Glossary*, <http://glossary.istqb.org/> (Apr. 25, 2018).

Jovanović, I. (2006). "Software testing methods and techniques." *The IPSI BgD Transactions on Internet Research*, 30.

Judy McKay, Matthias Hamburg, and ISTQB Glossary Working Group (Eds.). (2016). *Standard Glossary of Terms used in Software Testing: Version 3.1*. International Software Testing Qualifications Board.

Laugwitz, B., Held, T., and Schrepp, M. (2008). "Construction and Evaluation of a User Experience Questionnaire." *HCI and Usability for Education and Work*, A. Holzinger, ed., Springer Berlin Heidelberg, Berlin, Heidelberg, 63–76.

Laugwitz, B., Schrepp, M., and Held, T. (2006). "Konstruktion eines Fragebogens zur Messung der User Experience von Softwareprodukten." *Mensch und Computer 2006*, H. M. Heinecke and H. Paul, eds., OLDENBOURG WISSENSCHAFTSVERLAG, München.

Sauro, J. (2011). "Measuring Usefulness." *MeasuringU*, <https://measuringu.com/usefulness/> (Mar. 30, 2018).

Müller, T., Friedenberg, D., and ISTQB WG Foundation Level. (2011). *ISTQB certified tester-foundation level syllabus*. International Software Testing Qualifications Board.

Nielsen, J. (1993). *Usability Engineering*. Morgan Kaufmann, Amsterdam, the Netherlands.

Nielsen, J. (2012). "Usability 101: Introduction to Usability." *Nielsen Norman Group*,

<https://www.nngroup.com/articles/usability-101-introduction-to-usability/> (Mar. 14, 2018).

Noori, N. S., Wang, Y., Comes, T., Schwarz, P., and Lukosch, H. (2017). "Behind the Scenes of Scenario-Based Training: Understanding Scenario Design and Requirements in High-Risk and Uncertain Environments." *Proceedings of the 14th ISCRAM Conference*, T. Comes, F. Bénaben, C. Hanachi, M. Lauras, and A. Montarnal, eds., Albi, France, 948–959.

Perlman, G. (2015). "User Interface Usability Evaluation with Web-Based Questionnaires." <http://garyperlman.com/quest/> (Mar. 7, 2018).

Sandvik, K. B., Jacobsen, K. L., and McDonald, S. M. (2017). "Do no harm: A taxonomy of the challenges of humanitarian experimentation." *International Review of the Red Cross*, 99(904), 319–344.

Sauro, J. (2011). "10 Essential Usability Metrics." *MeasuringU*, <https://measuringu.com/essential-metrics/> (Mar. 8, 2018).

Sauro, J. (2015). "SUPR-Q: A Comprehensive Measure of the Quality of the Website User Experience." 10(2), 19.

Nielsen, J. (1994). "Severity Ratings for Usability Problems: Article by Jakob Nielsen." *Nielsen Norman Group*, <https://www.nngroup.com/articles/how-to-rate-the-severity-of-usability-problems/> (Apr. 1, 2018).

"System usability scale." (2017). *Wikipedia*.

"Types of Software Testing for Dummies." (2013). *The Official 360logica Blog*, <https://www.360logica.com/blog/types-of-software-testing-for-dummies/> (Mar. 6, 2018).

"Usability and user experience surveys." (2016). *EduTech Wiki*, <http://edutechwiki.unige.ch/en/Usability_and_user_experience_surveys> (Mar. 7, 2018).

Van de Walle, B., and Comes, T. (2014). "Risk accelerators in disasters." *International Conference on Advanced Information Systems Engineering*, Springer, Cham, Switzerland, 12–23.

Van de Walle, B., and Comes, T. (2015). "On the nature of information management in complex and natural disasters." *Procedia Engineering*, 107, 403–411.

"What is a White Box Testing?" (2012). *Software Testing Class*, <http://www.softwaretestingclass.com/white-box-testing/> (Mar. 17, 2018).

"White Box Testing." (2010). *Software Testing Fundamentals*, <http://softwaretestingfundamentals.com/white-box-testing/> (Mar. 16, 2018).

Supporting firefighter training through visualising indoor positioning, motion and time use data

Jo Dugstad Wake*
NORCE
jowa@norceresearch.no

Barbara Wasson
SLATE / University of Bergen
barbara.wasson@uib.no

Edvard Pires Bjørgen
SLATE / University of Bergen
edbjorgen@gmail.com

Fredrik Vonheim Heimsæter
SLATE / University of Bergen
fredrik.heimseter@uib.no

ABSTRACT

Providing feedback to smoke divers following their training exercises is constrained by limitations on the opportunities for observation by instructors, as the buildings are filled with smoke. Yet, sensors that can be used to track and provide data on various aspects of the smoke divers training are becoming available. This paper describes a study of how to support firefighters and their instructors with visualisations of their training performance. The study has involved the development of a training support tool, FireTracker, that visualises data from firefighters smoke diving activity, and an evaluation of FireTracker in use. FireTracker uses data from sensors such as Bluetooth Beacons and gyroscopes to detect and visualize the smoke diver's movement and work patterns during smoke diving exercises. We found that there is a training need for these visualisations, but clear limitations on the positioning data that currently can be provided.

Keywords

Smoke diver training, multimodal data, data visualisations

INTRODUCTION

Global satellite navigation systems (GNSS) have become widespread, providing positioning data from several, separate yet combinable (Zhang et al. 2013) systems for the general public, and there are a plethora of applications and systems that build on them. GNSS data are not suitable for indoor localisation, however, mainly because of the need for skywards line-of-sight to obtain data, and data disturbances caused by presence of buildings (Yassin et al. 2017). Indoor positioning technologies (IPS) are still developing. While GNSS systems work more or less the same way, IPS systems are technologically much more diverse and rapidly changing (Brena et al. 2017; Liu et al. 2007), and the ideal IPS technology depends on the purpose and use situation. This study represents an endeavor to utilise IPS enhanced by additional sensor data, to visualise indoor movement and work performed by smoke diver during training exercises, with the purpose enhancing the post-exercise evaluations.

This paper describes the development and evaluation of a tool, FireTracker, that provides data driven ICT-support for firefighter and smoke diver training. The overall goal for the study has been to develop ways of supporting training for smoke divers with data based visualisations of their smoke diving activity, with emphasis of movement, to improve training efficiency and enhance the post exercise evaluation sessions. The goal for the tool is to combine different sensor data to create visualisations of the indoor training activity of cold smoke diving. The visualisations are intended to be used by instructors and firefighters to retrospectively assess and evaluate training performances. At the current stage of the study we have developed a first working prototype of FireTracker that provides tracks of the smoke diver's movement, activeness, and time use on locations in a house during smoke diving training

*corresponding author

exercises. Firetracker has also been evaluated in use during a cold smoke diving exercise. The paper addresses the 2019 ISCRAM Advanced Technologies for First Responders workshop topics of (1) emerging mobile trends in first responder technology, and (2) multimodal data fusion, representation, and visualisation.

As a study about improving the conditions for self-reflection and learning, the underlying pedagogical rationale for development is inspired by Computer Supported Collaborative Learning (CSCL) (Koschmann 2012), a perspective on learning that emphasises the social, goal-driven and artefact-mediated nature of human activity. As an initiative to develop support for group-oriented learning and training in the workplace, our study also takes a data-driven and analytics approach to understanding learning, and is influenced by the field of Learning Analytics (LA) (Siemens 2013). In an overview of the field of LA (Misiejuk and Wasson 2017) find that there are a number of examples of using LA to understand small-group learning processes, although (Ruiz-Calleja et al. 2017) point out that there is a lack of studies taking an analytics approach to understanding learning in the workplace. For example, (Goggins et al. 2015) visualised activity analytics from student group work in order to give feedback to teachers, so they could provide support or make relevant interventions in their students work. Another example is (Martinez-Maldonado et al. 2017), who studied nurses mobility in healthcare simulations. (Worsley 2018) argues that using mobility data is an emerging trend within multi-modal learning analytics.

The approach of using sensor data visualisations to improve and enhance the training of first responders and firefighters is novel, although there are examples of using digital indoor navigation support for actual firefighting (Fischer and Gellersen 2010). Getting "lost inside" or, becoming disoriented inside a burning building is one of the most common sources of accidents and injury in firefighting (Fischer and Gellersen 2010). (Ojeda and Borenstein 2007) describe a non-GPS based navigation support system directed at walking persons, for example for first responders inside buildings. By inserting an Inertial Measurement Unit in the wearers' boots, the system uses gait to predict movement. The system feeds the data to a central control, that can build an overview, for example, of rooms that have been visited in a building. (Koch et al. 2007) have used RFID to build a system for locating humans and objects indoors, although not directly for firefighters. (Feese et al. 2013) developed a smartphone based sensing system for monitoring temporal and behavioral performance in firefighting missions. Their goal was to use the collected data to compare the performance metrics between firefighter teams participating in the same mission. They used sensors on smartphones to sample data which was stored on the smartphone and transmitted the data so it could be used for real-time monitoring.

(Fortenbacher et al. 2017) used physical and environmental sensor data to capture and understand the emotional states of firefighters in training, and how the data can be used to support self-regulatory learning. In other studies not explicitly focused on training, it has been studied how networked robots and sensors (Kumar et al. 2004) and communication networks (Wilson et al. 2007) could be utilized to expand firefighters and other first responders situational awareness. (Wang et al. 2015) describe a firefighter training system utilizing sensors embedded in the firefighters training clothes, as a way of interacting with a VR game. When nearing a fire in VR, temperature sensors increases the temperature within the clothes. (Backlund et al. 2007) and (Lebram et al. 2009) have also taken a game-based approach involving sensors and haptic feedback to firefighter training. Through the cave-based game Sidh, firefighters can train smoke diving using their own bodily movements as input, and receive feedback on surrounding screens. Evaluation of the game with firefighters highlighted the highly motivational aspect of this mode of training.

iComPAss

The study has been carried out as part of the iComPAss (inquire Competence for better Practice and Assessment) project (Netteland et al. 2016). At many workplaces training and learning is a continuous process, that includes courses, training exercises, further education, certification, and re-certification, and is often integrated with work processes. The training and learning takes place to increase the employees and the organization's competences, and is particularly relevant for firefighters who dedicate much of their workday to training and honing skills. The iComPAss project studies data (i.e., evidence) based decision making by examining how digital tools that use competence modelling, learning analytics, and visualizations can support decision making within healthcare and firefighting.

The questions that have guided the research are:

- How does FireTracker affect and support firefighter training?
- How can data from FireTracker support and enhance the evaluation of smoke diving exercises?

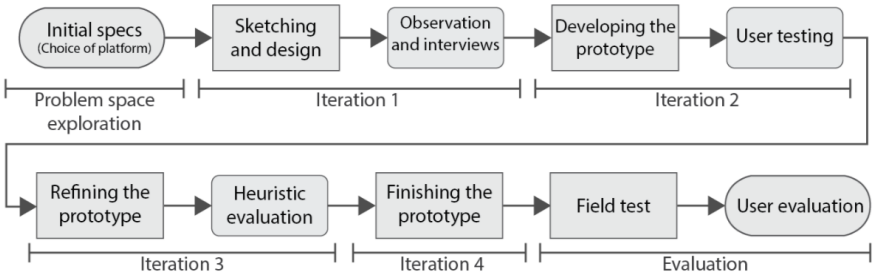


Figure 1. Overview of the development process

METHOD

The development process has been inspired by the perspectives of design science (Hevner et al. 2004), and Human Computer Interaction, and we have taken a data-driven and iterative approach to development. The approach to development is particularly inspired by the Interaction design life cycle, as described by (Preece et al. 2015), where design requirements are turned into design alternatives, which are developed into prototypes, which are then evaluated, forming the basis of new understanding of the requirements.

The research and development was carried out in collaboration with a firefighter department located in Western Norway. We interacted mainly with firefighters in three roles: smoke divers; smoke dive exercise leaders; and, departmental training officer. To understand the problem space, and the particular needs and contingencies of smoke dive training, we studied firefighter training manuals, observed and took part in smoke diving exercises and post-exercise evaluations, and interviewed exercise leaders and smoke divers about firefighter training needs in semi-structured interviews, throughout the development process. The smoke divers and exercise leaders have also given direct feedback on the different versions of the prototypes in interview sessions, following training exercises. All interviews were recorded and transcribed, and field notes were written following observations.

Early prototypes were evaluated using Nielsen's heuristics (Nielsen and Molich 1990), and we carried out our own testing of beacon precision and localisation algorithms. The development was carried out in four phases (see Figure 1), and included (1) problem domain understanding and requirements specification, (2 & 3) developing and refining the prototype, and (4) developing the currently final version.

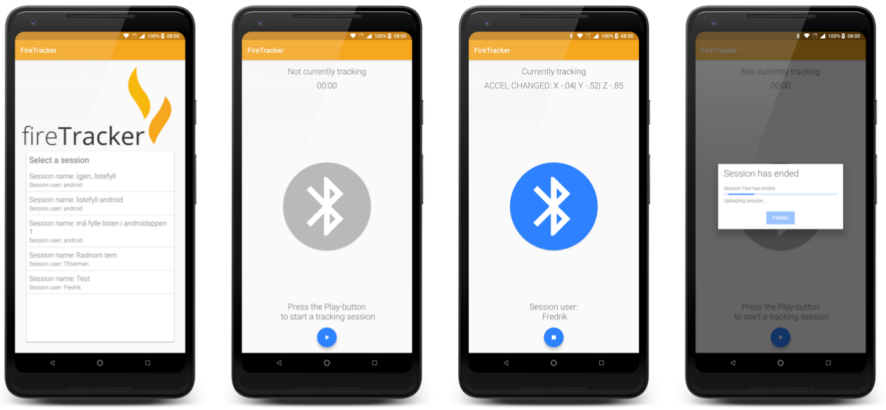
The final version was evaluated as a field trial (Brown et al. 2011) in a dedicated smoke diving exercise, where we tested different configurations of BLE beacon placement, and assessed how these affected the localisation visualisations. Two instructors and two smoke divers took part, using their regular equipment. Following the exercise, they were interviewed on usability and usefulness issues, and they also evaluated FireTracker using the System Usability Scale (Brooke 2013). One of the exercise leaders had evaluated earlier versions, while one used FireTracker for the first time. The two smoke divers used it for the first time. The results from the field trial are presented in the section "Evaluating FireTracker".

FIRETRACKER

FireTracker is a smoke diver data capture and visualisation tool, used to create data-driven improvements in training smoke diving. FireTracker has two main components: 1) an app to capture data from different sensors (Figure 2), and 2) a learning authoring tool, to be used by instructors to set up training exercises, and present the resulting visualisations during post-exercise evaluation sessions (Figure 3). The app is installed on a mobile phone attached to the smoke diver, and the authoring tool is (usually) installed on an iPad carried by the training exercise leader.

Requirements

The rationale for FireTracker is that smoke diving takes place according to a set of standards and heuristics for communication, movement pattern, order of the work, etc. The standards exist to ensure firefighter safety and efficiency in an otherwise hazardous environment. By nature, these activities are carried out in partial or total blindness for both the instructor/exercise leader and the firefighters. By creating visualisations of how these activities are carried out in practice, and making them available for inspection and discussion immediately after the exercise, we can increase smoke divers ability to understand and discuss how a particular exercise went, and better support post-reflections on the training activity.



(a) Session list (b) Tracking activity (c) Active tracking (d) Session uploading

Figure 2. The FireTracker Mobile Interface

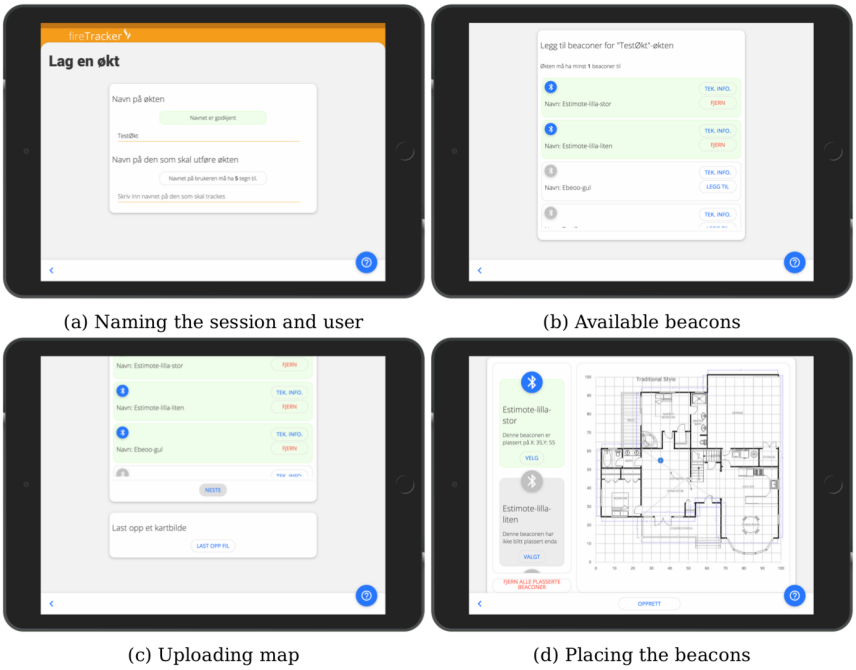
Requirements for FireTracker were developed and refined throughout the design and development iterations, in close conversation with exercise leaders, overall training leaders, and smoke divers. The most important requirements were:

- Portability: FireTracker should facilitate rapid deployment at any site, rather than be installed in a fixed location, as the firefighters avoid training cold smoke diving at any one location for too long. For the firefighters, it is an important aspect of the training to avoid becoming too familiar with the layout of a building, and that the deployment phase doesn't become routine. This requirement limited the choice of positioning technology; it is generally easier to integrate position technology in a fixed building or site (Li et al. 2014) than to rely on a portable system.
- Transportability: The physical equipment should be easy to bring along on an exercise, and not require a lot of time to set up by the exercise organisers. Any physical equipment should not restrict firefighter movement, or be in the way of the smoke divers in the building.
- Build on handheld devices: The firefighter department that took part in the study already uses handheld devices for various purposes during both their exercises, and in responding to emergencies. All their vehicles are equipped with iPads. They also carry out their post smoke dive evaluations immediately after the exercise, at the location of the exercise. To support the feedback and evaluation session, visualisations should be available for display right away, and to be passed around in a circle, rather than require a desk- or laptop computer.
- Data presentation efficiency: The data visualisation tracks should be easy to read, and provide a clear and precise picture of the smoke diver movement inside a building filled with smoke.

Infrastructure and sensors

FireTracker consists of (1) an app for tracking a set of Bluetooth Low Energy (BLE) beacons on a mobile phone to gather positioning data, and (2) a web-based administration tool on a tablet, to enable the exercise leader to set up FireTracker for the exercise, and have a suitable screen for visualising the data. BLE beacons are placed around the building that is the site for the exercise, and the mobile phone is attached to the helmet of each smoke diver.

FireTracker builds datasets from the set of BLE sensors placed around a building and the gyroscope and accelerometer sensors on the mobile phone, and the mobile phone clock. When the firefighters search through the building, the mobile phone collects data from the beacons and combines it with data from the mobile phone sensors, which are used for determining if the firefighters are moving their head or walking. During development we discovered that sometimes during exercises the smoke divers would stand still/not walk. The reasons for not walking varied, for example for sorting out confusion, or for searching for casualties. Usually, the reason for not walking carried significance to their activity, and we found to interesting to attempt to capture more aspects of non-movement. Thus we needed additional sensor data. The mobile phone accelerometer was used to detect and estimate the number of steps taken by the smoke diver. By comparing the number of steps taken in a time interval, it was possible to



(a) Naming the session and user (b) Available beacons

(c) Uploading map (d) Placing the beacons

Figure 3. The FireTracker administration tool

determine whether the smoke diver was moving or standing still at a location. The gyroscope was used to determine relative orientation of the device. By using the same method as with the accelerometer to determine movement, it was possible to compare the time interval with the gyroscope orientation values to see whether the smoke diver was rotating the device at any time. The data are visualised as a track on a map of the building indicating the path of the smoke diver during the exercise. The track is enhanced with mobility data from the gyroscope, in addition to the time use data. Steps and head movement are visualised as yes/no buttons tied to each location, and time use is visualised as a weighted dot on the track – the larger the dot, the longer the stay.

The positioning algorithm can be described as proximity positioning, based on the received signal strength of the beacon. The mobile app constantly scans a list of available beacons. It connects to the beacon with the strongest signal, from the list of available beacons specified in the administration tool before the exercise starts, and creates a location for that beacon. The beacon has a known location on a map. It calculates the time it has been connected to the current beacon, in addition to the other sensor data, as long as that beacon emits the strongest signal. When a stronger signal is received from another beacon, it creates a new location, and adds the data from the previous location to a list of locations. Different approaches to data cleaning were experimented with during the development process, to create as clear and accurate tracks as possible.

Using FireTracker

Figure 3 illustrates FireTracker administration tool in use. To set up an exercise, the exercise leader uses the administration tool to create a session (session translates to exercise) and entering his or her name (Figure 3a). Then, he or she searches for available beacons, and include them in the session (Figure 3b). Next a map of the building is uploaded (Figure 3c). The map is easily created by either taking a picture of the floor plan of the building (usually available near the floor entrances in public buildings), or creating a map of the floor plan by hand beforehand. Finally, beacons are placed throughout the building (Figure 3d), and their position is recorded by tapping on a spot on the corresponding map. Each beacon is represented by a blue dot on the map.

The sessions are selected on mobile phones, which in turn are attached to the firefighters' helmets. Figure 2, a-d illustrates a use cycle of the tracking app. Before starting the smoke dive, the app is set to start recording data on the mobile phone. During the smoke dive, the app tracks data from BLE beacons, gyroscope, accelerometer and clock. After the exercise has been completed, the data are uploaded and rendered as a track on the map of the building, which also visualises use of time and activity level at each position. The administration tool is designed to work on an iPad, to better support the physical aspect of moving around and being on your feet, which is very much a part of the exercise both for the instructors and firefighters.

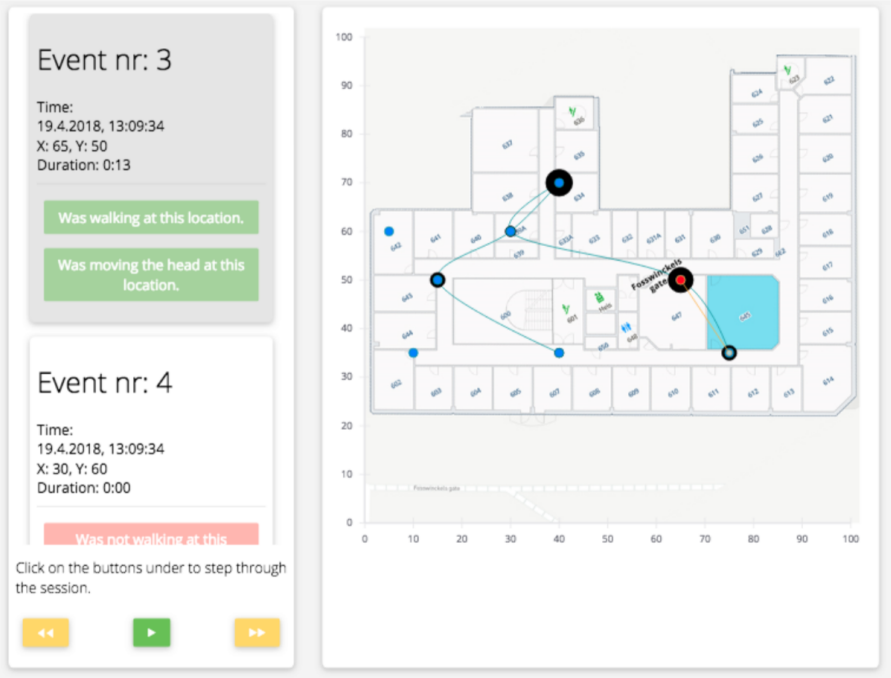


Figure 4. FireTracker Data Visualisation

The administration tool then produces a map of the activity, as can be seen in Figure 4, one for each smoke diver. The visualisation shows how the firefighters have moved in the building, illustrated as a series of locations (the circles). The blue dots represents the beacons, and if the circle is enhanced by a encompassing black circle, the location is deemed to have been visited. The movement can be replayed as a linear track, using the green "play" icon in the bottom left corner of the screen. The track can also be replayed by clicking on the list of events. Additional information is tied to each location. The size of the circle indicates for how long the location was visited – the larger the circle, the longer the stay. The red centre at one of the locations in Figure 4, represents that it is currently selected for viewing. "Playing" the track will have the red dot jump through all the locations in the order they were visited. The boxes on the left displays more information about each location, such as a time stamp, map coordinates, duration of stay, whether the firefighter was walking around or standing still at the location, and finally whether the firefighter was moving his or her head. The left boxes correspond to the red-dotted location on the map.

EVALUATING FIRETRACKER

FireTracker was evaluated in a field trial as described in the methods section. The main goal of the field trial was to understand how FireTracker affected and supported the smoke diving exercise self-evaluations, and to understand whether the data visualisations were useful for their training. In the field trial we first introduced FireTracker to the participants, and explained the purpose of the tool. One of the instructors was familiar with the tool, and had evaluated previous versions, the other three were new to FireTracker. Then we surveyed the site and building, and drew a floor plan to be used as the map by hand, as the particular building we used (an abandoned office building), didn't have a floor plan illustration available. The instructor who was previously unfamiliar with FireTracker set up the BLE beacons, and chose where to place them based on his understanding of how they worked.

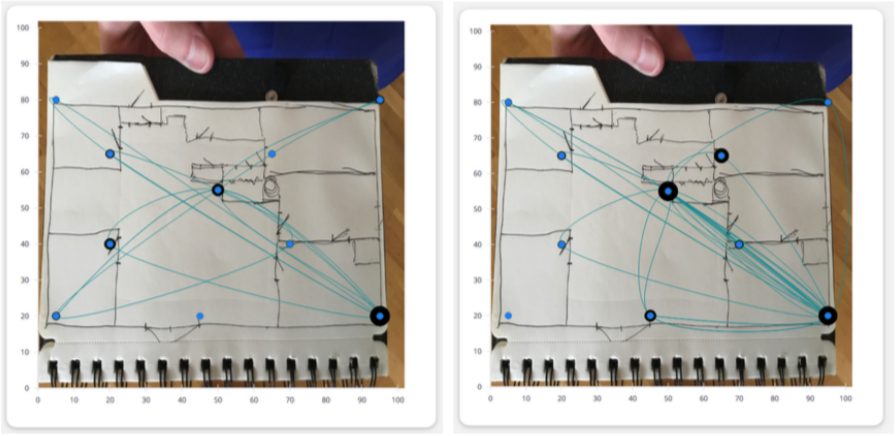
Four cycles of smoke dives augmented by FireTracker was carried out for the field trial. The cycles varied with smoke diver blinding method and equipment use, BLE beacon placement in the building, and on the roles assigned to the smoke diver (called "Smoke diver 1" and "Smoke diver 2"). Smoke diving always happens in pairs, and the tasks tied to the roles 1 and 2 are different; which smoke diver leads, which smoke diver searches rooms for missing persons whilst the other smoke diver pulls the firehose and so on. The first smoke dive was not carried out with smoke in the building, but by covering the helmet visors, which allowed the researchers to directly observe the smoke dive from within the building. The specifics of each cycle are presented in Table 1.

Results

This subsection presents the results from the field trial. The presentation of the results is divided between location tracking accuracy and value, and verbal feedback from smoke divers and instructors.

Table 1. Field trial exercise cycle

Exercise session	Equipment and blinding method	Number of participants
1	No smoke, helmet visors covered	Smoke divers: 2 Instructors: 2
2	Cold smoke, with full gear	Smoke divers: 2 Instructors: 2
3	Cold smoke, with full gear	Smoke divers: 2 Instructors: 2
4	Cold smoke, helmet only	Smoke diver: 1 Instructor: 1



(b) Smoke diver 1, exercise session 2

(c) Smoke diver 2, exercise session 2

Figure 5. Smoke dive tracks

Location tracking

As a test of the precision of the location tracks from the smoke diving, the field trial produced disappointing results. The tracks did not reflect the route chosen by the smoke divers, and made it seem like they were moving between locations to a high degree, whilst they actually were moving in a circular, clockwise pattern from right to left. The cause of the problem with the localisation was that the mobile phone intermittently picked up stronger signals from beacons that weren't the closest, producing tracks that did not reflect the path of the diver during the exercise. This happened because the location algorithm uses the beacon's known location on a map to position the user, and the user is deemed to be closest to the beacon with the strongest signal. There was also some "jumping" between beacons, resulting in a track that gave the appearance that the smoke divers walked back and to the same location.

One useful aspect of the tracking and smoke diving activity that FireTracker can be read from the tracks, can be seen in Figure 5, and can be related to the role distribution between the smoke divers. The figure shows the tracks from the second session of the exercises, for Smoke Diver 1 and 2. In the second session, both smoke divers walked the same route, but Smoke Diver 2 had the role of searching rooms, whilst Smoke Diver 1 pulled the firehose, and was more stationary when the pair was not advancing between the rooms. The track visualisations indicate more movement by Smoke Diver 2, which aligns with his role of entering and searching through each room.

Feedback from smoke divers and instructors

The smoke divers were asked questions about whether the visualizations gave them more information about the exercise and their own performance, and how it contributed to the internal evaluation of the exercise, in separate semi structured interviews. The evaluation with the smoke divers focused on wearing the mobile phone, tracking, and the resulting visualisations. The smoke divers both highlighted that FireTracker didn't require much from them, and that they concentrated on their routines during the exercise, which is in line with our goal for FireTracker to be pervasive to the exercise whilst tracking. They both gave the feedback that the tracks were too imprecise to be of value. One of the smoke divers found the presentation of the movement (as movement between the blue dots) a little confusing, and would have preferred a footpath-like track of his movement. *It (FireTracker) would have helped me appreciate more about my movement in the building. But I would have preferred a tail (visualisation). That would have made it easier for me to see where I had been. I would have understood more easily. Almost like playing*

a movie, one and one dot appearing. And preferably in two colours, one for me and one for (colleague). They both gave the feedback that the data visualisations would have been very useful if they had been more precise. The smoke divers SUS results were 67,5 and 57,5, both below the accepted score of 68.

The evaluation with the two instructors was focused on use of the administration tool, in addition to the tracking app and visualisations. They found that it was easy to use, and the instructor who had never used it before reported that "*I didn't need a manual, I figured out how to use it after a couple of minutes*". Both reported that the data would be very useful in exercise evaluation, but were currently too imprecise, and they wouldn't be able to identify errors in the smoke diver movement with the current level of granularity. One of the instructors made a similar comment to one of the smoke divers; that he would have preferred to have the localisation nodes in the visualisations appear in the same order they were visited, rather than all at once.

Regarding expectations to how they could use FireTracker, the chief training instructor responded that he sees it as a tool for inspecting or verifying the activity of the smoke divers, and as a starting poing for a discussion with the smoke divers: *It would be very good for learning about their (the smoke divers) search patterns, to see if it matches the theory. They are supposed to make a plan before entering, and with this tool you can check if they follow it. Did they follow the wall to the right, or turn around? If so, why? It would be a very useful tool for that.* He also had the idea that they could place artefacts in the house, such as training dolls and similar items, and match the track visualisation against the artefacts in the evaluation. He also thought it would be useful for the smoke divers themselves to see their own data. The other instructor commented that it would improve their basis for providing feedback to the smoke divers, and that data from one team could increase the training value to the teams that waited outside (buildings are searched sequentially by teams of two, and when one team runs out of air they exit, the next team takes over). The total SUS score for the instructors were 82,5 and 90, although they underscored that they answered under the assupmtion that the data had been precise.

Discussion

Beacon precision and track visualisation : As part of an infrastructure of a system to support indoor localisation not tied to one specific place, the beacons used in our study, in the way we have used them, currently seem to provide too imprecise data to support precision tracking. The beacon signal strength that our algorithm build on was affected by a number factors such as mobile phone make and obstruction of physical objects, resulting in unpredictable data. During development we experimented with several ways of increasing precision, such as manipulating the signal strength in digital and physical ways, and different types of placement. This finding is in line with (Fischer and Gellersen 2010), who describes the accuracy of indoor positioning systems along the two axis of precision and portability, where an increase in portability leads to less precision and vice versa. One of the main design requirements behind the development in this study, was that the localisation technology needed to work in conditions (i.e. buildings) that were unknown beforehand.

Based on their response in the interviews, our chosen way of visualising progress within the building was not intuitive to the smoke divers. Our method created a location at each placed beacon, indicated by a dot placed on the map. The algorithm was intended to create a line between all the locations/dots that were visited, which in turn could be played step-wise retrospectively. The firefighters responded that they would have preferred a caterpillar-like track that increased in length as time progressed, relative to where they were in the building. Early interviews gave us differing inputs on the requirements for actual precision, but the general opinion was that the movement visualisation only had to be somewhat accurate to be of value, as long as it was correct. Here, it is possible that the sensor errors we experienced as described above contributed to confusion in interpreting the visualisation, as there positioning data indicated movement that hadn't occurred.

Capturing non-movement: As discussed in the section on FireTracker infrastructure, the study started with the goal of capturing smoke divers indoor movement during exercises. The goal was to improve and create new opportunities for discussions between smoke divers and instructors in the post exercise evaluations, and was based on the observation that their movement and search patterns are set according to standards and competencies, yet there are limits on observation. Following observation of a full scale smoke diving exercise, and their following exercise evaluation at an early stage in the development process, we realised that there were additional important aspects of non-movement. During the evaluation session, they discussed events that had caused pauses in the search, because this was when there were situations and problems to solve. Or in other words, a search without any stops would be "everything as normal". We saw the opportunity to uncover further aspects of the smoke diving activity using the gyroscope, accelerometer and time measurements. The imagined scenario was that when a search pauses, we could provide metrics on their physical activity levels and time use, which could enhance discussions about why the momentary stop in the search took place. A large circle at a location, would for example indicate that they had stayed there for long. While the time use data is represented intuitively, the activity level data are not detailed

enough. Our current version displays these data as "yes" or "no" to walking and head movement at each location, and future versions will display these data in more detail, indicating amounts of steps and head movement.

Conclusions

The field testing of FireTracker during a training exercise revealed that both the instructors and the firefighters thought the tool was very useful. The smoke divers found the performance data on their activity interesting, and the instructors appreciated the idea behind the visualisations and found the system very easy to use, although the localisation tracks were to imprecise with our current version of FireTracker. Further development of the tool will include better quality visualisations and localisation precision, and the investigation of the use of learning analytics to identify patterns of good and bad movement so that they can be flagged to the instructors and firefighters.

REFERENCES

Backlund, P., Engstrom, H., Hammar, C., Johannesson, M., and Lebram, M. (2007). «Sidh: a Game Based Firefighter Training Simulation». In: *2007 11th International Conference Information Visualization (IV07)*, pp. 899–907.

Brena, R. F., Garcia-Vazquez, J. P., Galvan-Tejada, C. E., Munoz-Rodriguez, D., Vargas-Rosales, C., and Fangmeyer, J. (2017). «Evolution of Indoor Positioning Technologies: A Survey». In: *Journal of Sensors*, e21.

Brooke, J. (2013). «SUS: A Retrospective». In: *J. Usability Studies* 8.2, pp. 29–40.

Brown, B., Reeves, S., and Sherwood, S. (2011). «Into the Wild : Challenges and Opportunities for Field Trial Methods». In: *CHI 2011*. CHI '11. Vancouver: ACM Press, pp. 1657–1666.

Feese, S., Arnrich, B., Troster, G., Burtscher, M., Meyer, B., and Jonas, K. (2013). «CoenoFire: Monitoring Performance Indicators of Firefighters in Real-world Missions Using Smartphones». In: *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. UbiComp '13. New York, NY, USA: ACM, pp. 83–92.

Fischer, C. and Gellersen, H. (2010). «Location and navigation support for emergency responders: A survey». In: *IEEE Pervasive Computing* 9.1, pp. 38–47.

Fortenbacher, A., Pinkwart, N., and Yun, H. (2017). «[LISA] learning analytics for sensor-based adaptive learning». In: *Proceedings of the Seventh International Learning Analytics & Knowledge Conference on - LAK '17*, pp. 592–593.

Goggins, S., Xing, W., Chen, X., Chen, B., and Wadholm, B. (2015). «Learning Analytics at "Small" Scale: Exploring a Complexity-Grounded Model for Assessment Automation». In: *Journal of Universal Computer Science* 21, pp. 66–92.

Hevner, A., March, S., Park, J., and Ram, S. (2004). «Design Science Research in Information Systems. , 28(1), 75-105.» In: *MIS Quarterly* 28.1, pp. 75–105.

Koch, J., Wettach, J., Bloch, E., and Berns, K. (2007). «Indoor Localisation of Humans, Objects, and mobile Robots with RFID Infrastructure». In: *7th International Conference on Hybrid Intelligent Systems (HIS 2007)*, pp. 271–276.

Koschmann, T. (2012). *CSCL: Theory and practice of an emerging paradigm*. New York: Routledge, p. 368.

Kumar, V., Rus, D., and Singh, S. (2004). «Robot and sensor networks for first responders». In: *IEEE Pervasive Computing* 3.4, pp. 24–33.

Lebram, M., Backlund, P., Engstrom, H., and Johannesson, M. (2009). «Design and Architecture of Sidh. A Cave Based Firefighter Training Game». In: *Design and Use of Serious Games*. Ed. by M. Kankaanranta and P. Neittaanmaki. Dordrecht: Springer Netherlands, pp. 19–31.

Li, N., Becerik-Gerber, B., Krishnamachari, B., and Soibelman, L. (2014). «A BIM centered indoor localization algorithm to support building fire emergency response operations». In: *Automation in Construction* 42, pp. 78–89.

Liu, H., Darabi, H., Banerjee, P., and Liu, J. (2007). «Survey of wireless indoor positioning techniques and systems». In: *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews* 37.6, pp. 1067–1080.

Martinez-Maldonado, R., Power, T., Hayes, C., Abdiprano, A., Vo, T., and Buckingham Shum, S. (2017). «Analytics meet patient manikins: challenges in an authentic small-group healthcare simulation classroom». In: *Proceedings of LAK'17: the Seventh International Learning Analytics & Knowledge Conference*. Vancouver, pp. 90–94.

Misiejuk, K. and Wasson, B. (2017). *State of the Field report on Learning Analytics. SLATE Report 2017-2*. Tech. rep. Bergen: Centre for the Science of Learning & Technology (SLATE)., p. 76.

Netteland, G., Wasson, B., Hansen, C., and Hirnstein, M. (2016). «Learning analytics and open learning modelling for professional competence development». In: *NOKOBIT - Norsk konferanse for organisasjoners bruk av informasjonsteknologi* 24.1, pp. 1–5.

Nielsen, J. and Molich, R. (1990). «Heuristic Evaluation of User Interfaces». In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '90. New York, NY, USA: ACM, pp. 249–256.

Ojeda, L. and Borenstein, J. (2007). «Non-GPS Navigation for Security Personnel and First Responders». In: *Journal of Navigation* 60.3, pp. 391–407.

Preece, J., Rogers, Y., and Sharp, H. (2015). *Interaction Design : Beyond Human-computer Interaction*. 4th. Wiley.

Ruiz-Calleja, A., Prieto, L. P., Ley, T., Rodríguez-Triana, M. J., and Dennerlein, S. (2017). «Learning Analytics for Professional and Workplace Learning: A Literature Review BT - Data Driven Approaches in Digital Education». In: ed. by É. Lavoué, H. Drachsler, K. Verbert, J. Broisin, and M. Pérez-Sanagustín. Cham: Springer International Publishing, pp. 164–178.

Siemens, G. (2013). «Learning Analytics: The Emergence of a Discipline». In: *American Behavioral Scientist* 57.10, pp. 1380–1400.

Wang, M., Yu, F., Jang, R., Ma, S., and Zhao, Y. (2015). «Development of firefighting training clothes based on embedded wireless sensors». In: *Proceedings of the 2015 International Conference on Automation, Mechanical Control and Computational Engineering* 124, pp. 638–643.

Wilson, J., Bhargava, V., Redfern, A., and Wright, P. (2007). «A Wireless Sensor Network and Incident Command Interface for Urban Firefighting». In: *2007 Fourth Annual International Conference on Mobile and Ubiquitous Systems: Networking & Services (MobiQuitous)*, pp. 1–7.

Worsley, M. (2018). «Multimodal analytics then and now». In: *Companion Proceedings 8th International Conference on Learning Analytics & Knowledge (LAK18)*, pp. 1–16.

Yassin, A., Nasser, Y., Awad, M., Al-Dubai, A., Liu, R., Yuen, C., Raulefs, R., and Aboutanios, E. (2017). «Recent Advances in Indoor Localization: A Survey on Theoretical Approaches and Applications». In: *IEEE Communications Surveys & Tutorials* 19.2, pp. 1327–1346.

Zhang, S., Lahaye, F., and Heroux, P. (2013). «A comparison between GPS-only and combined GPS+GLONASS Precise Point Positioning». In: *Journal of Spatial Science* 58.2, pp. 169–190.

Track 13.

Privacy Risk Management in Critical Infrastructures

Chairs,

Jordi Forné Muñoz, *Universitat Politècnica de Catalunya, Spain*

Javier Parra Arnau, *Universitat Rovira i Virgili, Spain*

CoRe and WiPe Papers – Privacy Risk Management in Critical Infrastructures

Proceedings of the 16th ISCRAM Conference – València, Spain, May 2019

Zeno Franco, José J. González and José H. Canós, eds.

Renouncing Privacy in Crisis Management? People's View on Social Media Monitoring and Surveillance

Larissa Aldehoff, Meri Dankenbring, Christian Reuter
Science and Technology for Peace and Security (PEASEC), TU Darmstadt
aldehoff@peasec.tu-darmstadt.de; reuter@peasec.tu-darmstadt.de; www.peasec.de

ABSTRACT
Social media is used during crises and disasters by state authorities and citizens to communicate and provide, gain and analyze information. Monitoring of platforms in such cases is both a well-established practice and a research area. The question, whether people are willing to renounce privacy in social media during critical incidents, or even allow surveillance in order to contribute to public security, remains unanswered. Our survey of 1,024 German inhabitants is the first empirical study on people's views on social media monitoring and surveillance in crisis management. We find the willingness to share data during an imminent threat depends mostly on the type of data: a majority (63% and 67%, respectively) would give access to addresses and telephone numbers, whereas the willingness to share content of chats or telephone calls is significantly lower (27%). Our analysis reveals diverging opinions among participants and some effects of sociodemographic variables on the acceptance of invasions into privacy.

Keywords
Social Media, Privacy, Security, Crisis Management, Surveillance.

1 INTRODUCTION

Data in social media shared by inhabitants can be very useful for state authorities such as police, fire and rescue organizations in cases of crises and disasters, which is also shown by the fact that social media are a crucial part of ISCRAM research. Analyzing all ISCRAM papers related to social media from 2004-2018 Reuter et al. (2018), found that the papers predominantly examine social media posts in English, mostly posted on Twitter. Geographically, the analysis focused on crises in Europe and North America. Another conclusion is that in order to realize broader analyses of social media content, it will be necessary to overcome the obstacle of "even more complicated data-extraction scenarios" (Reuter et al. 2018). This obstacle is a consequence of the current increase in awareness for privacy issues and resulting changes in online behavior, as well as terms of use. Examples in point are the growing popularity of discarding Facebook's public post search feature and of the sandbox mode on Instagram. The European General Data Protection Regulation (GDPR) efficiently curbed the amount of user data that is publicly accessible for processing. Moreover, the above-mentioned debate on privacy may lead to a decrease in people's willingness to having their online behavior analyzed (Reuter et al. 2018). Notwithstanding the usefulness of data collected from social media and by surveillance measures in cases of crisis and disaster, privacy concerns have to be considered when using this data for crisis management. One part of this complex issue is the people's perception of privacy.

Therefore, this paper addresses the research question: *How far are people willing to provide their data in social media and accept surveillance to support authorities in cases of crisis and disaster?* We provide answers to the question which types of data people are more concerned to share and under what conditions they are willing to make their data available. Additionally, we ask about people's opinions on several surveillance measures aimed at increasing public security in cases of imminent threats. Some of those measures are already practiced in Germany or elsewhere, others are still broadly and controversially discussed.

Through a representative survey of 1,024 respondents, we found that German inhabitants were only partially willing to give up their privacy on social networks and, depending on the crisis context, would give specific authorities access to non-intimate but private data. Nevertheless, this disposition to (partially) waive privacy to support state authorities' crisis management goes hand in hand with the demand of holding the state accountable:

inhabitants want increased transparency of data collection as well as rights regarding the use of collected data by state authorities. We analyzed sociodemographic factors of our subjects such as gender, age and educational background and their influence on the answers given. By means of simple regression analyses we partly found correlations, partly no correlations between these criteria. Overall, there is a tendency for subjects to cooperate on certain conditions such as transparency of monitoring and selection of data transmission.

In the beginning of the paper we outline the state of research concerning social media in crisis management and users' perception of privacy in social media and surveillance (section 2). We will continue with the methodology (section 3) and the results of our analysis (section 4), followed by a conclusion and implications for further research (section 5).

2 STATE OF RESEARCH

The following section reflects the current state of research concerning social media as a tool in crisis management as well as on public perceptions of privacy concerning social media monitoring and surveillance. Moreover, it presents the research gap we aim to address.

2.1 Social Media in Crisis Management

Social media are becoming more sophisticated by the day. This is not only true for social media in day-to-day use, but also their employment in cases of emergencies (Reuter, Hughes, et al., 2018; Reuter & Kaufhold, 2018). Information technology plays a major role in context of peace and security (Reuter, 2019). The first use of social media for purposes of disaster support documented and detected by the authors took place in 2001. Since then, the use of social media has increasingly intensified, provoking a growing amount of research on the topic. It has analyzed different cases and users, practices and tools with diverging methodologies. A main goal being the support of actors involved in crises, emergencies or disasters, depending on their nature and size. The research and advancements made so far are summarized under the term of crisis informatics (Hagar, 2007; Palen et al., 2009).

Reuter & Kaufhold (2018) found studies emphasizing the role social media played in the handling of a significant majority of large emergencies in the last decade, and even in most emergencies since 2001. Although many studies initially focused on the US, research studying other continents is making up ground, thus enabling systematic comparisons across countries, regions and kinds of emergencies. Nonetheless, most studies still focus on Twitter, which is possibly due to the ease of data selection on the platform. Reuter & Kaufhold's (2018) analysis was centered on the analysis of different usage patterns, such as communication between citizens (i.e. C2C), communication from authorities to citizens (i.e. A2C), communication from citizens to authorities (i.e. C2A) and between authorities (A2A). It is important to note that the perception of social media varies across users, i.e. diverges between authorities and citizens. Although both tend to pose similar challenges, such as a lack of trust and knowledge, citizens still expect that authorities monitor social media. Thus, expectations have to be aligned in order to overcome existing problems. Due to the almost omnipresent nature of social media and its low entry and usage barriers ,"the role held by members of the public in disaster (…) is becoming more visible, active, and in possession of greater reach than ever seen before" (Palen & Liu, 2007). Each citizen can post information about an event, thereby helping the authorities and other citizens. The willingness to use voluntarily communicated information is ambiguous. Reuter & Spielhofer (2017) investigated the reasons why citizens do not use social media for crisis communication and identified them as "mistrust as well as the perceived lack of a clear purpose for using social media in emergencies" (Reuter & Spielhofer, 2017).

In addition to the positive aspects of social media collaboration between citizens and public authorities, there are also negative aspects, as illustrated by the case of the Munich rampage in the summer of 2016. While the gunman was hunting for people in the shopping center, eyewitnesses posted a number of videos on Twitter and Facebook virtually live. The police later criticized these actions on social channels, considering them to have unsettled and panicked the population. In addition, the perpetrator could have been informed about the ongoing police operation as well as countermeasures of the emergency services. A helpful communication tool such as social media can only be used effectively if actors are aware of consequences of certain courses of action (see Dobel, 2016; Schillat, 2016). In emergencies people are usually willing to help, but still do not want to be monitored.

2.2 Perception of Privacy in Social Media and Surveillance

Social media do not only pose chances, rather, looking at crisis management, there are several problems, risks and challenges (Kaufhold & Reuter, 2019). The revelations of Edward Snowden or the Cambridge Analytica affair are just two broadly discussed examples for the potential misuse of data and show the pressing relevance of privacy. One important aspect of privacy is its perception by users. The existing research on the privacy paradox suggests that people are willing to limit or even renounce their privacy for relatively small benefits, or even none

at all (Norberg et al., 2018). But further research showed that this approach is too narrow. First of all, it has to be noted that users do not necessarily understand that they are sharing personal data to be able to use "free" social networks, services and apps (Turow et al., 2015). Additionally, they lack knowledge on the consequences of sharing their data, and if so, are unable to regain control over data already shared (Acquisti & Grossklags, 2006). Therefore, users do not make an informed and deliberate choice. Even users who are aware of this, often do not see an alternative and share their data because the effort to search for and use other services is considered as to large by users, e.g. because of fast-changing terms of use (Buxmann, 2015, p. 143) As a result, they feel that they are losing control over their data (Degli-Esposti et al., 2017). One example is a value-driven approach to privacy. Buxmann focuses on the value people attach to their data. He surveyed users' opinions on data driven business models in social networks and their behavior if they disapprove of those. In 2012, 62% and in 2014 even 75% of respondents disapproved such business models – at the same time only 14%, especially older users, refused to use those services (Buxmann, 2015).Simultaneously, users appear to refuse to pay a significant amount of money for more privacy-friendly services. This can be explained with the privacy paradox, but factors such as awareness, knowledge, motivation and considered effort need to be analyzed in more detail than this concept allows.

The picture crystallizing of people's perception of surveillance is similar to the one of privacy in social media. Often people perceive surveillance as an inevitable art of the digital revolution. Even if they are aware of it, they think they need to accept it to avoid important social or economic disadvantages (Turow et al., 2015). Only a minority of people "try to avoid, evade or circumvent surveillance by adopting different strategies, from the intentional provision of inaccurate information, to the adoption of anonymization and privacy-preserving tools" (Degli-Esposti et al., 2017). Ball stresses that although people tend to do little to counter surveillance, this does not mean that surveillance is meaningless for them. It may be accepted or even approved of because providing data can satisfy individual anxieties, or patriotic or participative values. Another factor is that there is often no identifiable observer who exercises perceivable control. Furthermore, the pleasure of performative display overrides the scrutiny that comes hand-in-hand with self-revelation (Ball, 2009, p. 641).

Looking at surveillance from the privacy angle, Kasper (2005) introduces a sophisticated typology of privacy breaches, which will be introduced in further detail below, and finds that forms of intrusions are covered with different intensities in US newspapers. Thus, the public perception of privacy strongly depends on the context and on the type of invasion in it, and is subject to change: Kasper (2005) finds that – possibly due to historical events and changes in state practice – perceptions of invasions into privacy changed in the period of 1990 to 2003, for example increasing the relevance of clandestine forms of data gathering in the public debate (which she calls *stockpiling*).

2.3 Research Gap

Research on the question when and under what conditions people are willing to either, allow the state access to a well-defined set of information on them, restricted to the period of time constituted by a severe crisis or disaster, or, grant the state rights to conduct long-term surveillance efforts, in order to increase public security – remains unanswered by previous research. Reuter & Spielhofer (2017) indicate that mistrust and lack of a clear purpose are reasons for people to reject using social media in emergencies. It remains unclear under what conditions inhabitants support their use if this improves crisis management. The research of Degli-Esposti et al. (2017) shows that the "current security policies and solutions are somehow perceived as inadequate by citizens, whose demands, opinions and perceptions need to be further explored" (Pavone et al., 2017). Kokolakis demands further research in his work to "build a clearer picture of the relation between privacy attitudes and behavior" (Kokolakis, 2017). Therefore, this paper addresses these questions concerning conditions and kind of data as well as the view on surveillance measures.

3 RESARCH DESIGN AND METHODOLOGY

This paper addresses the yet unclear perception of privacy by people concerning social media monitoring and surveillance in cases of crisis. In 3.1 we outline our theory approach and the design of survey questions, 3.2 explains the survey design and conduction and 3.3 presents the respondent's characteristics.

3.1 Theory and Design of Questions

To be able to contribute to the perception of privacy we use Kasper's approach of privacy. She identified several problems with existing definitions of privacy: 1) definitions appear to be not properly specified, i.e. they are too broad or too narrow, 2) they have a strong cultural bias and 3) "tend [...] to be value-driven" (Kasper, 2005). Therefore, she developed a typology of privacy by understanding privacy "from the standpoint of its invasion" (Kasper, 2005). This typology for invasion accounts "for all possible ways in which one's privacy can be invaded and to identify distinctive characteristics associated with each type of invasion" (ibid.). Our interest expands over the typology's categories e*xtraction* and *observation*. To measure public perception of forms of *observation*, the

third question (called Q13, for the exact wording of the questions see Fig. 1-4) on different fictional laws was asked. The question addresses *observation*, because the state is granted intrusive rights to collect and store information on and metadata generated by its citizens, which comprises different forms of surveillance. Kasper (2005) defines *observation* to "mainly consist of 'watching,' [which] refer[s] to surveillance in general" (Kasper, 2005). She subclassifies *observation* into *physical observation* (i.e. "surveillance of a physical entity" (ibid.), e.g. by surveillance cameras), *communication observation* (i.e. "the interception and/or surveillance of communication in any form: telephone, mobile phone, e-mail, fax [...] and so forth" (ibid.)) and *behavioral observation* (i.e. "the explicit monitoring of a behavior" (Kasper, 2005), such as "track[ing] consumers' buying *habits*" (ibid.)). Question 13 addresses these forms of *observation* separately, by first asking whether respondents would be willing to grant the state the right to surveil them via CCTV (*physical observation*), via internet communications (*communication observation*) and lastly, all information available, which includes the former two, but adds the possibility of observing *behavioral* habits. Nonetheless, the differentiation of the categories is made difficult by the fact that both physical and communication observation include the possibility to observe individual's habits. Therefore, we will not draw any conclusions on the perception of behavioral observation as a single category, but rather as an implicit possibility taken into account by respondents when answering the questions on the first two, and particularly when considering exhaustive surveillance methods.

We will continue by considering types of information *extraction*, defined by Kasper (Kasper, 2005) as "involv[ing] a deliberate effort to obtain something from an individual or group" (Kasper, 2005). Here, opposed to observation (i.e. surveillance), data is not collected over a long period of time, but situationally and with particular effort. To measure public perception of forms of *stockpiling*, Q11 on fictional state access to private information in times of crisis was asked. The question addresses *stockpiling*, because the state is granted intrusive rights to collect and store information on its citizens, which in and of itself, is not harmful for the individuals concerned. This access however is limited in time, here to the acute crisis situation. The data is not automatically used, but stored and potentially used to ensure people's wellbeing. Though agreeing to the access to their information, people "remain largely unaware and uninformed of what happens to the information after it has been collected" (ibid.). *Appropriation/disclosure* is not covered by the questionnaire, because the state has no reason to collect potentially damaging personal information in order to disclose it later on (Kasper, 2005).

Inner-state extraction is covered by Q14, asking whether and in which cases people are willing to give up parts of their privacy in social media in order to track terrorists. The data collected is meant to provide information of the political and religious views of individuals, as well as their mental state or willingness to harm members of the public. These are not "externally knowable" (ibid.), and the judgement made on their basis decides over whether further policing steps are taken or not. Thus, the "stakes are higher than in *stockpiling*, and the purpose more specific than in *appropriation/disclosure*" (ibid.). Individuals are "usually aware of this" (ibid.), as the presence of laws allowing intrusion of this sort is known (particularly in case of the respondents who are made aware of it by the question), however (in line with Kasper's definition) it is possible that people are ignorant of the intrusion or its scope.

In her analysis of newspaper articles discussing intrusions into privacy from 1990 to 2003, Kasper (2005) finds that while data extraction is discussed most (constantly over 50% of newspaper articles), its percentage shows a declining trend. Observation however, takes increasing importance in the debate of privacy intrusions, whereas intrusion roughly stagnates (Kasper, 2005). Taking a closer look at extraction, i.e. dividing it into its subtypes, Kasper (2005) finds that while appropriation/disclosure used to be the main type discussed in the 1990s, its importance has sharply declined since. Not close to its importance in the 1990s, stockpiling is overtaking it in importance in 2003, so that the two categories roughly share the entirety of coverage on extraction in 2003. Of much smaller importance in the debate is inner-state extraction, not reaching the 10% mark of over-all privacy intrusion coverage. In the case of observation, levels of coverage are lower across categories, however physical and communication observation slightly gain importance across years (Kasper, 2005).

Kasper concludes that "[t]he instances of privacy invasion mentioned with increased relative frequency in the news are *stockpiling* extraction and *physical* observation" (Kasper, 2005). Putting this into the context of its time, i.e. 2003, we can conclude that the US' political situation of fear of terror and increasing surveillance is not unlike Germany's in 2018, although methods of surveillance have become significantly more sophisticated. Nonetheless, looking at the development of the possibilities and the debate induced by Snowden and other whistle-blowers, it can be speculated that the importance of observation in the discussion has since been increasing. Therefore, we expect to find similar, or possibly more extreme perceptions, especially regarding observation, as knowledge on security service practices of observation has increased since 2003. Kasper provides several explanations for this trend: surveillance takes place more often (ibid.), the consciousness of public has increased, therefore "people are more sensitive to such invasions" (ibid.) and the interaction of these two factors (ibid.). Concerning both types of privacy invasion (i.e. stockpiling and physical observation) people have "little knowledge and even less control" (Kasper, 2005). In addition, the already explained role of lacking awareness (Kasper, 2005) and a resignation

concerning *appropriation/disclosure extraction* and *autonomy intrusion* declined (Kasper, 2005).

3.2 Survey Design and Conduction

The study forming the basis of this paper is a representative survey of 1,024 subjects throughout Germany, adjusted according to the adult population from the age of 18 to 65 and the respective distribution of sociodemographic factors, namely gender, age, education, income, and region. It consists of an item-battery with four questions (Q11 to Q14) and lays its focus on privacy. Each question was designed to be Likert-scaled and closed-ended. The questions were developed based on a pilot study (Reuter et al., 2016). The hypotheses of this explorative study with 61 participants are tested with this quantitative approach.

The survey was conducted in German so that all participants understood the questions. The survey presented in this paper is a translation. Due to financial limitations no questions were included that checked the participants' attention or the frequency of their answers. The study was performed from 24th July to 7th August 2017.

3.3 Characteristics of Survey Subjects

The sample of survey respondents (N = 1024) was adapted to the distribution of gender, age, region, education, and income (Table 1) of the general German population by the preselection of an external survey panel provider (GapFish). In addition, solely consistent and complete answers were included. Therefore, our adapted sample consisted of 49.5% female (n = 507) and 50.5% male (n = 517) respondents. They were between 18 and 64 years old, nearly half of them being 45 and older (n = 492, 48%). Recruited participants live in all German federal states with the largest samples from North Rhine-Westphalia (n = 228, 22%) and Bavaria (n = 165, 16%). All participants are inhabitants of Germany, not necessarily German citizens. Furthermore, and important for this analysis, the subjects were classed based on their educational background: 69.2% of the subjects possess a secondary school graduation (from German Haupt- and Realschule). The other educational qualifications are distributed almost evenly over the remaining 30.8%. Only 1% (n = 9) of participants did not graduate from a school, while 15% (n = 160) held a degree from a university or college. Over two-thirds (n = 707, 69%) had an income between 1.500€ and 3.500€.

Table 1. Distribution of gender, age, education and income among participants.

Variables	Categories	Percent of respondents
Gender	Male	50.49
	Female	49.51
Age	18-24	11.82
	25-34	19.34
	35-44	20.70
	45-64	26.37
	65 and older	21.68
Education	No diploma	1
	General secondary school	33
	Intermediate secondary school	37
	High school diploma	14
	Polytechnic degree	7
	University degree	8
Income	Below 1,500	19
	1,500-2,500	29
	2,500-3,500	40
	Above 3,500	12

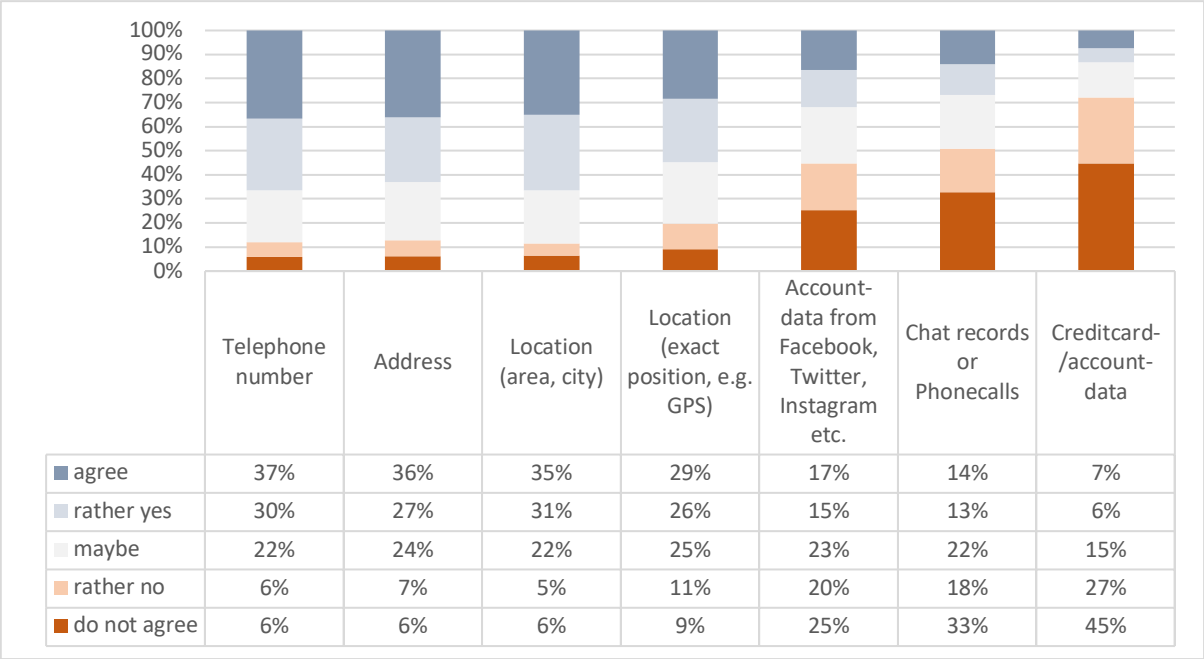
The responsible external survey panel provider recruited the respondents solely passively by advertising online (80%) and offline in TV commercials and newspapers (20%). There was no active recruitment via telephone or similar. The participants were chosen randomly and preselected concerning the above described criteria. They received small financial incentives between 0.5 and 2 Euros.

4 RESULTS

In the following sections, we present the results of our survey. The segmentation is based on the chronological structure of the item-battery, consisting of three questions concerning topics about the kind of personal data (potentially) accessed by state authorities, (fictional) state laws allowing surveillance and the conditions under which people would limit their privacy in social networks.

4.1 Access to Private Information by State Authorities

The first question (Q11) of the item-battery is: Which of your private data would you allow to be accessed by state authorities to combat an urgent crisis (e.g. terroristic attack or natural disaster)? The question is Likert-scaled: To each kind of private information, subjects were given different response possibilities. We included a wide range of information in order to assess peoples' general willingness to cede different private data. This allows us to roughly spot the average boundary of good will when it comes to sharing private information. Not all categories are therefore helpful to authorities in reality. A divide in the given answers is easily spotted, depending on the type of private data:



	Telephone number	Address	Location (area, city)	Location (exact position, e.g. GPS)	Account-data from Facebook, Twitter, Instagram etc.	Chat records or Phonecalls	Creditcard-/account-data
agree	37%	36%	35%	29%	17%	14%	7%
rather yes	30%	27%	31%	26%	15%	13%	6%
maybe	22%	24%	22%	25%	23%	22%	15%
rather no	6%	7%	5%	11%	20%	18%	27%
do not agree	6%	6%	6%	9%	25%	33%	45%

Figure 1: Access to Personal Information: Which of your private information would you allow to be accessed by state security services to combat an urgent crisis (terrorism, natural catastrophe) (Q11)?

The majority of the subjects would allow access to phone numbers, addresses and inaccurate GPS location data. In addition to this, accurate geolocations would be shared by most of the subjects as well. This approval of sharing private information sinks rapidly with other kinds of personal data: Access to profiles of social media accounts, contents of chats or telephone calls and financial account data would only be shared by a minority of subjects (Figure 1). Roughly 65% of the subjects agree to allow access to data like addresses, telephone numbers and geolocation-data, while only 32% would grant access to authorities to their social media profiles, 27% to contents of chats or phone calls, and only 13% would allow the mining of their financial account data (Figure 1).

4.2 Surveillance

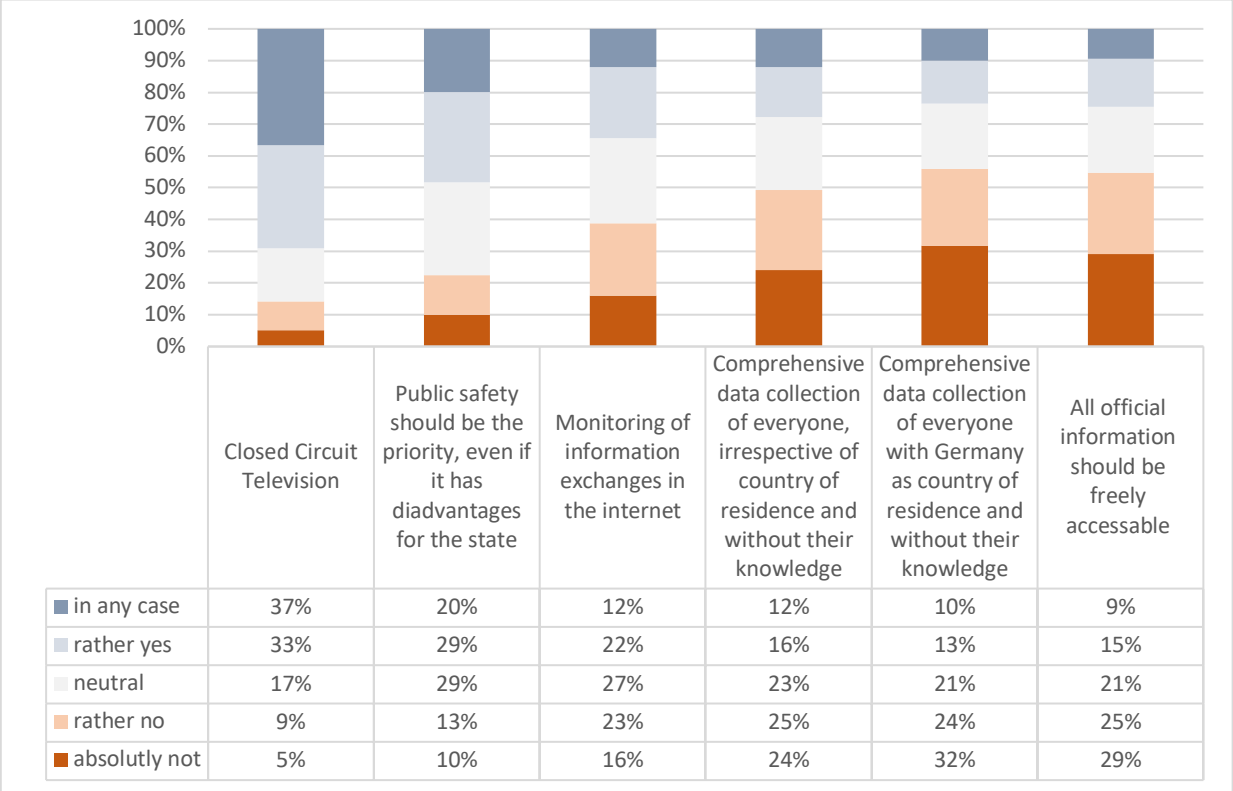
The third (Q13) question dealt with (fictional) state laws allowing surveillance, which were discussed in German mass media. Subjects were asked to support or reject those state laws. The question was whether authorities should have the following right to establish higher public security. We included this more general question in order to account for the fact that in reality, user data is not only assessed in times of acute emergencies, but also collected and used to prevent them. Public debate in Germany has mainly focused on this type of privacy intrusion, as well as the transparency and effectiveness of the measure. Therefore, the answers to this question indicate general willingness to give up data for the more or less definite, and highly subjective goal "security" is. Figure 2 gives an overview of the response possibilities and the answers given by the subjects.

Here too, there is a differentiated view regarding authority rights and the answers given: While the majority supports video surveillance of public spaces (approx. 70%) and the statement that public security should be paramount, even if this was adverse for the government (approx. 49%), the support falls for the rest of the stated laws and rights (Figure 2).

Monitoring of the internet and global information collections are considered ambiguously by the subjects, while the collection of information about German citizens without the knowledge of those involved is rather rejected. It is also striking that more than half of the subjects reject transparency in terms of a policy of freely available information about governmental intelligence for the public.

By bringing the variables into a binary form and creating a polarized mood image Figure 5 (in the Appendix) shows such a polarized tendency concerning the heavily debated issue of video surveillance. The majority of the subjects, 707 out of 853 (approx. 83%), would support video surveillance in public spaces.

Video surveillance in Germany is a frequent subject of debate in German media and therefore shall be examined in depth in Model 1. We see that people willing to allow surveillance of all exchange of information via the internet are significantly more likely to be in favor of introducing video surveillance. People opting for transparency (and against secrecy) on parts of the state, i.e. granting access to all information the state has, are significantly less likely (on a 1% level of significance) to opt for wide-spread video surveillance. Interestingly, people with a higher net income are significantly (on 1% level) more likely to favor video surveillance than people with a lower income.



	Closed Circuit Television	Public safety should be the priority, even if it has diadvantages for the state	Monitoring of information exchanges in the internet	Comprehensive data collection of everyone, irrespective of country of residence and without their knowledge	Comprehensive data collection of everyone with Germany as country of residence and without their knowledge	All official information should be freely accessable
in any case	37%	20%	12%	12%	10%	9%
rather yes	33%	29%	22%	16%	13%	15%
neutral	17%	29%	27%	23%	21%	21%
rather no	9%	13%	23%	25%	24%	25%
absolutly not	5%	10%	16%	24%	32%	29%

Figure 2: (Fictional) Rights of Officials: Should authorities in Germany in your opinion have or have not the right to the following to ensure public security better (Q13)?

Another subject of debate in German media is internet surveillance. 34% of the subjects rather support such surveillance, the rest rejects it. To have a closer look at the trends concerned, we use an OLS model of internet surveillance (see Model 2), i.e. granting the state the right to monitor all information exchange via the internet. People willing to allow video surveillance and notably, the collection of data on all people living in Germany without their knowledge, are significantly more likely (on 1% level) to opt for internet surveillance. Contradictorily, people both in favor of more transparency and more secrecy on parts of the state concerning the data it has, are significantly (on a 5 and 1% level, respectively) more likely to be positive about data gathering on information exchange via the internet. Simultaneously, having a higher education significantly (5% level) reduces the likelihood of opting for internet surveillance.

In Model 3, we regress respondents' disposition towards comprehensive data gathering on the entire population of Germany. While the answers to questions regarding video surveillance and secrecy in the perceptional part, and education and net income in the demographic part remain insignificant, questions such as allowing internet surveillance, international data collection and transparency are all positive and highly significant.

This points in an interesting direction: On the one hand, people who are prepared to allow the state highly intrusive access to their privacy are in other questions more likely to allow comprehensive data gathering. On the other hand however, people demanding transparency from the state - i.e. wishing that the state makes accessible all data it has on the population - expressly taking into consideration the adverse effect this might have on national security, are also significantly more likely to allow non-discriminatory, Germany-wide collection of data. Thus, transparency might be a necessary condition in the eyes of many skeptics to allow data collection in Germany.

This is an interesting point, because transparency and the accessibility of all data does not make the intrusion into privacy smaller, if anything, it increases it.

In the demographic part of the regression, age is the only variable with a significant effect (on 10% level), providing evidence that older people are more likely to allow comprehensive data gathering.

Table 2. OLS models of willingness to grant authorities privacy-intrusive rights

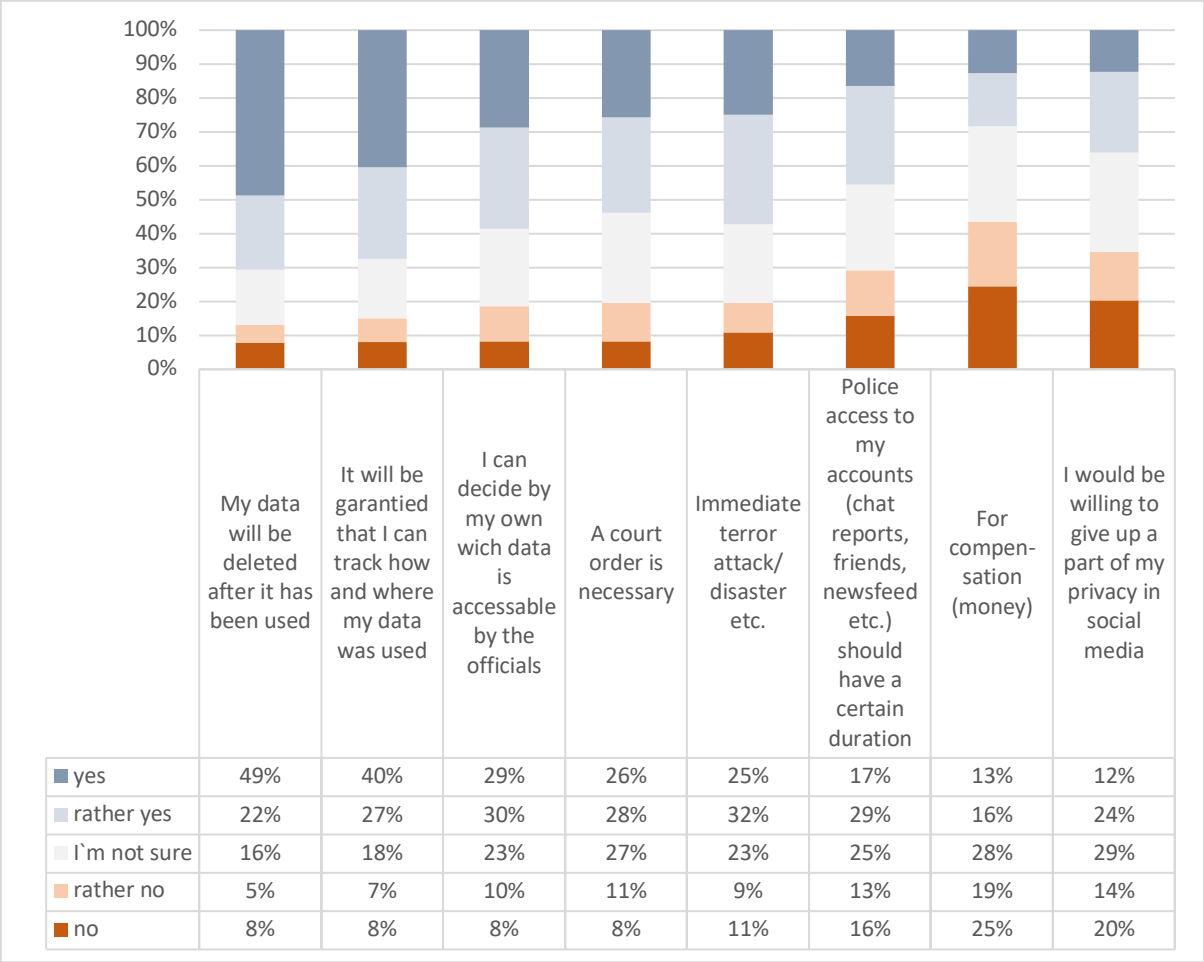
Variables	**Model 1** *Video Surveillance*	**Model 2** *Internet Surveillance*	**Model 3** *Data Gathering Germany*
Video Surveillance		0.281***	0.034
		(0.026)	(0.025)
Internet Surveillance	0.374***		0.386***
	(0.034)		(0.026)
Data Gathering Germany	0.053	0.458***	
	(0.039)	(0.031)	
Data Gathering World	0.055	0.046	0.475***
	(0.036)	(0.031)	(0.024)
Transparency	-0.121***	0.048**	0.086***
	(0.025)	(0.022)	(0.020)
Secrecy	0.177***	0.100***	0.039
	(0.030)	(0.026)	(0.024)
Age	0.021	-0.011	0.032*
	(0.023)	(0.020)	(0.019)
Education	-0.011	-0.051**	0.016
	(0.025)	(0.022)	(0.020)
Net income	0.101***	-0.039	0.006
	(0.033)	(0.028)	(0.026)
Constant	1.925***	0.422***	-0.577***
	(0.164)	(0.151)	(0.138)
N	1024	1024	1024
R^2	0.343	0.578	0.681
Adjusted R^2	0.337	0.575	0.679

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$

4.3 Security and Privacy

The last question (Q14) addresses whether respondents would give up parts of their privacy in social networks if this would include tracing of terrorist organizations, and if so, under which conditions. When looking at Model 4, we observe that the respondents with a high general willingness to give up their privacy are significantly less likely to favor the necessity of a court order for access to personal data (on a 1% level of significance). This tendency of people preferring well-defined, limited access to personal data opting for court orders applies to quite some variables. Among others it applies to people willing to share their personal data with the authorities only in the case of immediate emergencies, who are also significantly more likely to prefer court orders. Similarly, people willing to share personal data only if the duration of usage is clearly defined, are significantly more likely to support the necessity of court orders for access. Equally significantly positive is the effect of pledging for self-determined usage of data by authorities.

However, this trend of people with high standards of data protection is not as consistent as it might first seem. There is no significant connection between demanding the deletion of data after usage and preferring court orders. The same is true for the demand of transparency in the states' handling of personal data and court orders. Interestingly, people with higher age and education are also more likely to favor court orders as necessity to allow for access to personal information. The effect of education is not significant in either of the other two models. Age has a significantly positive effect (on 5% level) on making the deletion of data a necessary condition for access to personal data on social media, but not on sharing data in case of an immediate emergency.



	My data will be deleted after it has been used	It will be garantied that I can track how and where my data was used	I can decide by my own wich data is accessable by the officials	A court order is necessary	Immediate terror attack/ disaster etc.	Police access to my accounts (chat reports, friends, newsfeed etc.) should have a certain duration	For compen-sation (money)	I would be willing to give up a part of my privacy in social media
yes	49%	40%	29%	26%	25%	17%	13%	12%
rather yes	22%	27%	30%	28%	32%	29%	16%	24%
I`m not sure	16%	18%	23%	27%	23%	25%	28%	29%
rather no	5%	7%	10%	11%	9%	13%	19%	14%
no	8%	8%	8%	8%	11%	16%	25%	20%

Figure 3: Conditions of Renouncing Privacy: Would you be willing to waive parts of your privacy on social media when it was used to detect terrorists and, if so, under what conditions? (Q14)

Looking at Model 5 in greater detail, we see that all other answers given to the question described above, predict the answer to sharing data in cases of immediate emergency rather well. The only significantly negative effect can be observed with wishes for self-determination of the data used. All other positive answers, be they in favor of more privacy or not, have significantly positive effects. One answer that we should highlight in this context is granting a monetary incentive for sharing personal data. This demand has no significant effect in either of the other two models. Here however, people willing to sell their data are also significantly more likely to be willing to share their data on social media. The demographic controls are all insignificant. Furthermore, all people, be they defenders of data privacy or not, are willing to share their personal data in social networks in cases of emergencies. Notably, emergencies include both natural disasters and terrorist attacks. It could be argued that this effect might be driven by the mere inclusion of terrorist attacks into the scope of 'emergencies', as the debate on political violence, particularly Islamist violence, is increasingly securitized. The control question (Q12) asked on people's willingness to share their data on social media with the authorities across different types of emergencies however, contradicts this notion.

The deletion of data after usage, as modeled in Model 6, is significantly (on a 1% level) predicted by the willingness to share data in cases of emergency, the demand for more transparency on the part of the German state, a defined duration of usage, as well as self-determination in the scope of data used. The effects of demanding a court order and a high over-all level of privacy are not significant. This implies that having a high standard of privacy, as modeled by these two variables, does not significantly predict demanding the deletion of data. Nonetheless, we find that higher age significantly (on 5% level) increases the probability of answering that deletion of data is a necessary condition for sharing personal data.

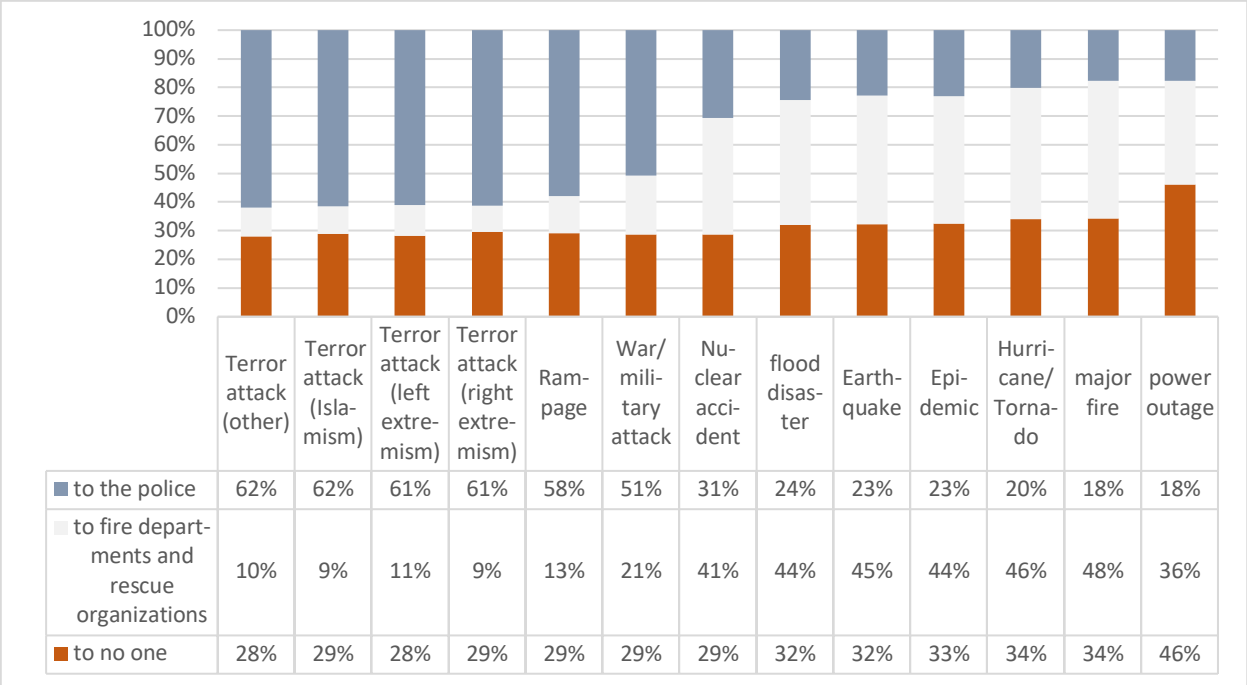


Figure 4: Situation differentiation: In the context of which acute threats would you waive parts of your privacy in social networks and to whom (e.g. by generally collecting private messages) and in which not? (To emergency response by the police, to emergency response not by the police (fire department, rescue teams), to nobody) (Q12)

Table 2. OLS models of willingness to give up privacy in social media

Variables	**Model 4** ***Court Order***	**Model 5** ***Immediate Emergency***	**Model 6** ***Deletion***
Privacy	-0.102***	0.293***	0.017
	(0.033)	(0.025)	(0.023)
Immediate Emergency	0.134***		0.176***
	(0.038)		(0.026)
Deletion	0.019	0.251***	
	(0.046)	(0.037)	
Transparency	0.071	0.165***	0.620***
	(0.046)	(0.038)	(0.025)
Court Order		0.090***	0.009
		(0.026)	(0.022)
Temporary	0.1***	0.144***	0.070***
	(0.031)	(0.026)	(0.022)
Self-determination	0.316***	-0.112***	0.076***
	(0.032)	(0.028)	(0.023)
Monetary incentive	-0.019	0.126***	-0.021
	(0.028)	(0.023)	(0.019)
Age	0.064**	0.036	0.049**
	(0.028)	(0.023)	(0.019)
Education	0.131***	-0.022	0.031
	(0.029)	(0.024)	(0.020)
Net income	0.020	-0.010	0.001
	(0.038)	(0.031)	(0.026)
Constant	0.918***	0.287*	0.196
	(0.208)	(0.172)	(0.144)
N	1024	1024	1024
R^2	0.225	0.507	0.652
Adjusted R^2	0.218	0.502	0.649

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$

5 DISCUSSION

So far, we presented the results of our work and made a first analysis of the gathered data. In the following sections we carry out a deeper examination of the findings. For this we return to our initial research questions and try to address the research gap.

5.1 Social Media in Crisis Management

Respondents are willing to cooperate with authorities and disclose information in situations of acute danger. Our models suggest that generally speaking, older and well-educated respondents are more likely to fall into the group of privacy-aware people. However, this trend is not constant and depends on the content made available to state authorities. In the case of an immediate terrorist attack, 74.5% of the subjects (when deleting neutral answers, n = 786) would give up their privacy in social media and make data accessible. Our insight on the context-sensitivity of subjects with regard to their willingness to provide information in crisis situations coincides with the findings of Ur et al. (2012). In this context, the central aspect of trust in the responsible authorities stands above all as a basis to the willingness to co-operate. This is also confirmed by Phelan et al. (2016) and Leon et al. (2015). The principle of context-dependency we have identified with regard to the information willingness of the subjects is also supported by various studies (Acquisti & Gross, 2006; Denning, 2014).

Overall, the willingness to disclose personal information in situations of acute danger (terror, war, natural disasters, etc.) is as follows: The more intimate the type of information, the lower the approval of the subjects. Telephone numbers, addresses and location information belong to the data that is not considered critically intimate and would be communicated by a large portion of subjects.

5.2 Perception of Privacy in Social Media and Surveillance

Regarding wishes and needs of citizens' concerning privacy as well as a possible monitoring of ethics by the state, we were able to obtain the following findings: More than half of the subjects approve of video surveillance of public space and regard public safety as a central task and the first and most important priority of the state (Figure 2, answer option "Security first"). Opinions in favor of video surveillance are made more likely by a generally positive view of surveillance, as approximated by consenting to internet surveillance and secrecy (as opposed to transparency), as well as a high net income. Possible causes for these views may lie in the Islamist terrorist attack by Anis Amri in Berlin in December 2016, or the various Islamist motivated attacks in Belgium, France or Great Britain since 2015. Especially the approval for video surveillance is plausible, since it has proven to be effective in relation to other crimes and their clarification. The general focus on security is also demonstrated by the fact that the subjects refuse public access to state information. Interestingly however, the relationship between opposing transparency and favoring surveillance is not constant.

Both data collection in Germany and on a global level are rejected by the subjects, especially the collection of information via internet is viewed critically by respondents. These could be impacts of the Snowden revelations, as well as general mistrust of internet surveillance measures, such as Degli-Esposti et al. (2017) describe it. But also with regard to this topic, large shares of neutral answers remain. This may be due to subjects not being sufficiently informed, simply not sure or in favor of measures for public safety but unable to oversee their consequences. Also, people endorsing transparency seem to be significantly more likely to consent to data gathering in Germany; although these two answer possibilities logically oppose each other in terms of security policy. All this makes clear that there is a need for enlightenment on measures to increase public safety. The same can be observed regarding the conditions for the abandonment of privacy: Above all, this means being aware of the nature of data potentially used by authorities. It becomes apparent, following Degli-Esposti et al. (2017), that subjects are not in need of an increased implementation of existing security measures, but rather a different implementation of existing and alternative security policies.

With regard to citizens' willingness to cooperate, we found that greater transparency and clarification by the authorities is required. Citizens are basically willing to make "superficial information", such as addresses and telephone numbers, accessible in dangerous situations. Given appropriate transparency on parts of the state, this also applies to parts of their privacy in social networks. The group opposing such measures seems to depend on the specific data to be shared. Although some models show the tendency that more educated and older people are less likely to share their data, this trend does not apply to model 3, which shows that older people are more likely to support Germany-wide surveillance. Similarly, a higher income raises the probability to support the implementation of video surveillance (model 1). A closer examination of the group in favor of privacy is necessary to make specific statements about the reasons underlying these trends. However, a non-linear effect of age on privacy attitudes might be a possible reason for what might seem at first sight to be contradictory outcomes. A first assumption can be made by relating to social media-affinity of the younger age groups and their need to express themselves on social media, while middle aged groups, not used to the openness of social media, are more likely to hide their private information. The older age groups could lack media expertise and therefore be willing

to share information (Reuter et al., 2017). Hence, the government has the obligation to provide specific education and enlightenment of its citizens, in order to increase their understanding of methods used by authorities. In this context, information transparency can be seen as a key factor to provide certain knowledge and foster a better understanding of these methods (Acquisti et al., 2015; Awad & Krishnan, 2006).

In general, a certain part of the population is prepared to give up parts of their privacy. People show a high willingness to share personal data in cases of immediate emergencies, even when demanding transparency, deletion of data, court orders, monetary incentives and self-determination about the usage of their data. At the same time, people with a low standard of privacy do not demand a law necessitating court orders for access to personal information.

Many neutral answers point out that the subjects have too little knowledge, are inhibited or simply cannot decide, respectively have concerns. In line with findings of Degli-Esposti et al. (2017; also see Kokolakis, 2017), a part of the respondents are not sufficiently informed to have an opinion. Especially the question concerning the willingness to give up parts of privacy in social media. Here, the most frequently chosen answer is "I'm unsure" (29%).

6 CONCLUSIONS AND PERCEPTIONS

In the following, we summarize the key findings of our study and focus on the most significant factors influencing the potential willingness of the subjects to cooperate. Finally, we discuss the limitations of our work, present possible perspectives for future research based on our findings and position our findings in the context of previous research.

6.1 Central Results: People Are Willing to Conditionally Give Up Privacy

The central question of our work on the willingness of the (German) population to resign parts of their privacy under certain conditions for crisis management and surveillance must be answered ambivalently. On the one hand, people are willing to do this to a certain extent. For this purpose, however, an adequate information-policy and transparency by authorities are needed. In particular, this includes self-determination in the use (about 59% consent) and confidentiality of the data, as for example the "right to be forgotten" allows (about 71% consent). Only then citizens no longer feel powerless and at the mercy of the state's surveillance activities.

A subject-related dichotomy with regard to the willingness to cooperate in social media in relation to the release of private information was identified above all by two characteristics: In particular, age and level of education have an influence on whether citizens make their private information available to the authorities. In terms of age, the regressions paint a diverse picture; age influences privacy-affinity positively in some respects and negatively in others. The educational level has a positive impact, however not constantly so: The higher it is, the more privacy-restricting authority rights are rejected (such as increased internet surveillance) and regulatory laws supported (such as court orders).

6.2 Limitations of our Work and Perspectives for Future Research

Our paper and the underlying survey have limitations concerning the methodological approach as well as the scope of the results. Because the survey was conducted online, neither an introduction nor any kind of background information were given to the participants. On the one hand, it must be stated that the respondents, although understanding the questions in general, did not necessarily understand the meaning of concepts used in the questions. On the other hand, this ensured unbiased answers of the respondents. However, in future research the used concepts should be introduced to participants to be able to get a more detailed and unambiguous insight into their mind set and opinion. Although a representation of the results and the subjects' socioeconomic properties are given, the online conducted survey only covers people who were willing to be part of this study. A bias towards internet affinity of the respondents is therefore possible. This would contradict the notion of the older participants lacking the necessary knowledge to be more critical towards surveillance. However, a general internet affinity does not necessarily imply an awareness for privacy. On the contrary, it can be assumed that people who are willing to register and share their opinion for a reward in such a panel are less concerned about their privacy than average citizens. Therefore, the analysis based on those participants is likely to underestimate skepticism towards privacy intrusions and the effect of education on it.

The sample is restricted to the German population, nonetheless our findings suggest to implicate more general correlations which may be apparent in other liberal democracies. Neither the expectations of German participants towards state authorities nor their interest in protecting their legal rights may be due to a specific German context. Furthermore, correlations between certain variables like income or education and people's attitude towards cooperation via social media may prove stable across borders as well. Nonetheless, the German historical background has to be taken into account, as it could cause a special relation to aspects of privacy and surveillance

by the state.

Our work can be elaborated with further questions regarding people's perception of privacy concerning social media and surveillance as our analyzed item-battery consisted of only three questions. Despite the meaningful results of our study, further and more in-depth questions are needed to interpret the neutral answer options. Relevant insights into the level of awareness people have concerning data exploitation and privacy intrusions in general, would encompass illuminating the reasons for people's opinions, as well as the consequences for their online behavior: The questions of why some people are more aware than others, and if higher awareness has any behavioral consequences are of central relevance. Moreover, the applied statistical methods, especially the multiple regression analyses, can be expanded. Qualitative methods should also be used to elaborate on this topic, especially to understand the neutral answers. Open questionnaires and interviews are suitable with a subsequent qualitative content analysis to cluster categories of the subjects. To get a deeper insight into the perception of privacy further research should focus on the connection between awareness for privacy and general knowledge about privacy issues, social media monitoring and surveillance measures.

6.3 Differentiation to Previous Research and Scientific Added Value

The theoretical premises of this paper are based on the work of Kasper (2005). We found that under some conditions (such as deletion after usage and transparency), a high number of people (26%) are willing to give up parts of their privacy in social media in order to detect terrorists. Thus, the threshold to allow for *inner-state* invasions (Kasper, 2005) is surprisingly low, given that the consequences (i.e. police measures against suspected terrorists) are rather severe. As shown in Model 5, in cases of emergencies even people with high standards for privacy (proxied by several conditions for state access to their data) are more likely to share their data. Keeping to forms of extraction, stockpiling, as covered by the first question (Q11), seems to be a differentially perceived form of privacy invasion. While most people are willing to share their address or telephone number, only few people are willing to share more intimate information, such as contents of chats or credit card details.

Now turning to forms of observation, a majority of respondents (70%) approves of *physical observation* as modeled by CCTV coverage of public spaces, whereas observation of *communication* and *behavior* are regarded critically by most. *Communication* was measured by granting the state access to exchanges of information via internet, which of course partly covers behavioral observation. The approval rate for this type of surveillance was 34%. An all-encompassing form of observation, i.e. gathering data on all German inhabitants without their knowledge, gained 23% positive answers. Thus, when combining several forms of *observation*, approval rates are particularly low. However, it needs to be kept in mind that with modern forms of communication and surveillance, every type of observation will reveal information belonging in either or both of the other two categories. Overall it can nonetheless be said that surveillance of communication and behavior, as well as extraction of intimate information, are particularly negatively perceived within the population. Keeping this in mind, it would be interesting to further examine people's opinions on data exploitation, as this encompasses most intimate data, but the discussion still has a very limited audience.

As Reuter & Spielhofer (2017) have shown, fundamental cooperation readiness is apparent but partly this seems to be associated with obligations of the state regarding transparency. We also considered the remarks by Degli-Esposti et al. (2017) on the unclarity of the population with respect to surveillance measures, the inherent frustration and the apathy-inducing effect on citizens.

ACKNOWLEDGEMENTS

This work was supported by the German Federal Ministry of Education and Research (BMBF) as well as by the Hessen State Ministry for Higher Education, Research and the Arts (HMWK) within CRISP as well as by the DFG within the CRC 1119 CROSSING.

We would like to thank Robin Gellert and Gordian Geilen for supporting the development of the survey items. In addition, their pilot study (Reuter et al., 2016) was a very valuable basis for this study.

REFERENCES

Acquisti, A., Brandimarte, L., & Loewenstein, G. (2015). Privacy and human behavior in the age of information. *Science*, *347*(6221), 509–514. https://doi.org/10.1126/science.aaa1465

Acquisti, A., & Gross, R. (2006). Imagined Communities: Awareness, Information Sharing, and Privacy on the Facebook. In G. Danezis & P. Golle (Eds.), *Privacy Enhancing Technologies* (pp. 36–58). Berlin, Heidelberg: Springer Berlin Heidelberg.

Acquisti, A., & Grossklags, J. (2006). What can behavioral economics teach us about privacy? In *ETRICS* (pp. 1–13).

Awad, N. F., & Krishnan, M. S. (2006). The Personalization Privacy Paradox: An Empirical Evaluation of Information Transparency and the Willingness to Be Profiled Online for Personalization. *MIS Quarterly*, *30*(1), 13–28. Retrieved from http://www.jstor.org/stable/25148715

Ball, K. (2009). Exposure: Exploring the subject of surveillance. *Information Communication and Society*, *12*(5), 639–657. https://doi.org/10.1080/13691180802270386

Buxmann, P. (2015). Big Data: Neue Geschäftsmodelle für die Future Internet Economy. In *Digitales Neuland* (pp. 139–153). Wiesbaden: Springer Fachmedien. https://doi.org/10.1007/978-3-658-09692-2_9

Degli-Esposti, S., Pavone, V., & Santiago Gómez, E. (2017). Aligning security and privacy - The case of Deep Packet Inspection. In M. Friedewald, J. P. Burgess, J. Čas, R. Bellanova, & W. Peissl (Eds.), *Surveillance, Privacy and Security: Citizens' Perspectives* (pp. 71–80). London, UK: Routledge. Retrieved from https://www.researchgate.net/publication/315657622_%0AAligning_security_and_privacy_-_The_case_of_Deep_%0APacket_Inspection

Denning, T. (2014). Human-Centric Security and Privacy for EmergingTechnologies. University of Washington.

Dobel, S. (2016). Pressesprecher im Porträt. Die Stimme der Münchner Polizei: Marcus da Gloria Martins.

Hagar, C. (2007). The information needs of farmers and use of ICTs. In B. Nerlich & M. Doring (Eds.), *From Mayhem to Meaning: Assessing the social a nd cultural impact of the 2001 foot and mouth outbreak in the UK*. Manchester, United Kingdom, United Kingdom: Manchester University Press.

Kasper, D. V. S. (2005). The evolution (or devolution) of privacy. *Sociological Forum*, *20*(1), 69–92. https://doi.org/10.1007/s11206-005-1898-z

Kaufhold, M.-A., & Reuter, C. (2019). Cultural Violence and Peace in Social Media. In C. Reuter (Ed.), *Information Technology for Peace and Security - IT-Applications and Infrastructures in Conflicts, Crises, War, and Peace*. Wiesbaden, Germany: Springer Vieweg.

Kokolakis, S. (2017). Privacy attitudes and privacy behaviour: A review of current research on the privacy paradox phenomenon. *Computers & Security*, *2017*(7).

Leon, P. G., Rao, A., Schaub, F., Marsh, A., Cranor, L. F., & Sadeh, N. (2015). Privacy and Behavioral Advertising: Towards Meeting Citizens' Preferences. In *Symposium on Usable Privacy and Security (SOUPS) 2015*. Ottawa, CAN.

Norberg, P. A., Horne, D. R., & Horne, D. A. (2018). The Privacy Paradox : Personal Information Disclosure Intentions versus Behaviors. *The Journal of Consumer Affairs*, *41*(1), 100–126. Retrieved from http://www.jstor.org/stable/

Palen, L., & Liu, S. B. (2007). Citizen Communications in Crisis: Anticipating a Future of ICT-supported Public Participation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 727–736). New York, NY, USA: ACM. https://doi.org/10.1145/1240624.1240736

Palen, L., Vieweg, S., Liu, S. B., & Hughes, A. L. (2009). Crisis in a Networked World: Features of Computer-Mediated Communication in the April 16, 2007, Virginia Tech Event. *Social Science Computer Review*, *27*(4), 467–480. https://doi.org/10.1177/0894439309332302

Pavone, V., Ball, K., Esposti-Degli, S., Dibb, S., & Santiago-Gómez, E. (2017). Beyond the security paradox: Ten criteria for a socially informed security policy. *Public Understanding of Science*, 0963662517702321. https://doi.org/10.1177/0963662517702321

Phelan, C., Lampe, C., & Resnick, P. (2016). It's Creepy, But It Doesn'T Bother Me. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 5240–5251). New York, NY, USA: ACM. https://doi.org/10.1145/2858036.2858381

Reuter, C. (2019). *Information Technology for Peace and Security - IT-Applications and Infrastructures in Conflicts, Crises, War, and Peace*. Wiesbaden, Germany: Springer Vieweg.

Reuter, C., Backfried, G., Kaufhold, M.-A., & Spahr, F. (2018). ISCRAM turns 15: A Trend Analysis of Social Media Papers 2004-2017. *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)*, (May), accepted.

Reuter, C., Gellert, R., & Geilen, G. (2016). Reception of Terror in Germany – Security, Privacy and Social Media. In Wohlgemuth, V., F. Fuchs-Kittowski, & J. Wittmann (Eds.), *Environmental Informatics – St ability, Continuity, Innovation. Current trends and future perspectives based on 30 years of history. Adjunct Proceedings of the EnviroInfo 2016 conference* (pp. 151–156).

Reuter, C., Hughes, A. L., & Kaufhold, M.-A. (2018). Social Media in Crisis Management: An Overview of Crisis Informatics Research. *International Journal on Human-Computer Interaction (IJHCI)*.

Reuter, C., & Kaufhold, M.-A. (2018). Fifteen Years of Social Media in Emergencies: A Retrospective Review and Future Directions for Crisis Informatics. *Journal of Contingencies and Crisis Management (JCCM)*, *26*, 1–17. https://doi.org/10.1111/1468-5973.12196

Reuter, C., Kaufhold, M.-A., Spielhofer, T., & Hahne, A. S. (2017). Social Media in Emergencies: A Representative Study on Citizens' Perception in Germany. *Proceedings of the ACM: Human Computer Interaction (PACM): Computer-Supported Cooperative Work and Social Computing*, *1*(2), 1–19. https://doi.org/10.1145/3134725

Reuter, C., & Spielhofer, T. (2017). Towards social resilience: A quantitative and qualitative survey on citizens' perception of social media in emergencies in Europe. *Technological Forecasting and Social Change*, *121*, 168–180. https://doi.org/10.1016/j.techfore.2016.07.038

Schillat, F. (2016). Der Social Media-Chef der Polizei München zu Facebook und Twitter: „Da dürfen wir uns nicht raushalten``. *MEEDIA (29.07.2016)*.

Turow, J., Hennessy, M., & Draper, N. (2015). *The Tradeoff Fallacy: How Marketers are Misrepresenting American Consumers and Opening Them Up to Exploitation*. Philadelphia. https://doi.org/http://dx.doi.org/10.2139/ssrn.2820060

Ur, B., Leon, P. G., Cranor, L. F., Shay, R., & Wang, Y. (2012). Smart, Useful, Scary, Creepy: Perceptions of Online Behavioral Advertising. In *Proceedings of the Eighth Symposium on Usable Privacy and Security* (p. 4:1----4:15). New York, NY, USA: ACM. https://doi.org/10.1145/2335356.2335362

Anonymizing Cybersecurity Data in Critical Infrastructures: The CIPSEC Approach

Ana Rodríguez-Hoyos
Universitat Politècnica de Catalunya (UPC)
Escuela Politécnica Nacional (EPN)
ana.rodriguez@epn.edu.ec

José Estrada-Jiménez*
Universitat Politècnica de Catalunya (UPC)
Escuela Politécnica Nacional (EPN)
jose.estrada@epn.edu.ec

David Rebollo-Monedero
Universitat Politècnica de Catalunya (UPC)
david.rebollo@entel.upc.edu

Jordi Forné
Universitat Politècnica de Catalunya (UPC)
jforne@entel.upc.edu

Rubén Trapero Burgos
ATOS
ruben.trapero@atos.net

Antonio Álvarez Romero
ATOS
antonio.alvarez@atos.net

Rodrigo Diaz Rodríguez
ATOS
rodrigo.diaz@atos.net

v1.1.1
2019/03/25

ABSTRACT

Cybersecurity logs are permanently generated by network devices to describe security incidents. With modern computing technology, such logs can be exploited to counter threats in real time or before they gain a foothold. To improve these capabilities, logs are usually shared with external entities. However, since cybersecurity logs might contain sensitive data, serious privacy concerns arise, even more when critical infrastructures (CI), handling strategic data, are involved.

We propose a tool to protect privacy by anonymizing sensitive data included in cybersecurity logs. We implement anonymization mechanisms grouped through the definition of a privacy policy. We adapt said approach to the context of the EU project CIPSEC that builds a unified security framework to orchestrate security products, thus offering better protection to a group of CIs. Since this framework collects and processes security-related data from multiple devices of CIs, our work is devoted to protecting privacy by integrating our anonymization approach.

Keywords

privacy, critical infrastructures, data anonymization, CIPSEC, security logs

*corresponding author

INTRODUCTION

Critical infrastructures (CIs) are either physical or virtual systems whose operation directly supports the functioning of a society. In fact, given the wide reach of critical infrastructures, even small problems on their operation could have a massive impact on a vast population (House 2013). Besides their reach, CIs are tightly coupled with sensitive areas such as health, telecommunications or economy, which are strategic for a country, so their interruption might imply severe affectation for citizens (House 2013). We are talking about the infrastructure of hospitals, transportation systems, oil and energy distribution systems, banking, environment monitoring, etc. Since these services are essential to the security, prosperity, and social welfare of the population, their corresponding CIs must not stop working and are usually managed by governments.

Given the importance of CIs, their information systems are usually strongly protected against intrusions, mainly against those coming from the Internet. Currently, the resources available for such protection involve "intelligent" cybersecurity solutions that “learn” how attackers behave and ultimately detect and stop future incidents. To do so, these solutions are fueled with so called logs, i.e., detailed information about past events, which are stored as records describing every security incident. Furthermore, logs from multiple sources are commonly shared among several devices and then aggregated so that more input information can improve the efficiency of protection . Aiming to ensure the continuity of their services, CIs have widely adopted such protection mechanisms that generate very detailed and vast information about the entities and interactions involved in security incidents.

Although more granular logs provide more intelligent security protection in CIs, inappropriate sharing of sensitive data may rise serious privacy concerns. Cybersecurity logs could include identifying attributes (IP addresses, user names, fingerprints, etc.), strategic information of companies (e.g., about vulnerabilities, software versions), and several other indicators (path names, user data) that, when disclosed, could easily be used to violate the privacy of the individuals or companies involved. The risk for privacy in this context is not only exacerbated by the increasing need of security services to aggregate shared cybersecurity data (to get improved protection mechanisms), but also by the large number of data items enclosed in cybersecurity logs.

Beyond the security they require to protect their information systems, CIs are more exposed to external attacks than conventional infrastructures due to a number of factors. First, since CIs commonly serve a large population, they are desired targets of attackers who aim at magnifying the impact of their offensive (Edwards 2018; Moyer 2010). Also, dealing with strategic processes and information, CIs are usually the target of high-level adversaries supported by powerful organizations and even governments (Swinford 2018; Woollaston 2017). These factors aggravate even more the effects of information leakage to the point that, e.g., the mere revealing of internal IP addresses or user names might imply severe risks for the integrity of such infrastructures. Interestingly then, the privacy of companies and individuals whose information is revealed in logs may have a direct impact on the security of CIs.

Our work is aimed at preserving the privacy of individuals and organizations in the context of the CIPSEC framework, and particularly in what involves the sharing of cybersecurity information. The EU project CIPSEC proposes a unified security framework to orchestrate state-of-the-art heterogeneous, diverse, security products aiming to offer high levels of cybersecurity protection. To do so, this framework is able to collect and process security-related data (logs, reports, events) so as to generate security anomaly alerts that can affect a CI health and that can have cascading effects on other CI systems. Our proposal includes a methodology and a tool (data privacy tool, DPT) for obfuscating sensitive data from cybersecurity logs to protect the privacy of the involved entities and individuals.

Namely, our DTP will modify sensitive data with the aim of *sanitizing* or cleaning it from too distinctive attributes. This involves applying several anonymization mechanisms to cybersecurity logs (suppression, generalization, pseudonymization) whose implementation will depend on the specific anonymized attributes.

THE CIPSEC FRAMEWORK

CIPSEC objectives

The main objective of the EU project CIPSEC is to create a unified security framework that orchestrates state-of-the-art heterogeneous, diverse security tools and offers high levels of cybersecurity protection in IT & OT Critical infrastructure environments. The framework is currently built to collect and process security-related data (logs, reports, events) so as to generate alerts for security incidents that can affect the integrity of a CI together with the potential cascading effect affecting other parts of the CI or event other CIs. The framework aims to be very flexible, adaptable and causing minimum interference to the normal operations of the CI, allowing for its easy updating when needed in a secure and easy manner.

The CIPSEC framework is capable of collecting events supported by different tools that monitor different aspects of the CI, such as network traffic, malware threats or wireless spectrum among others. Along with the operations for

collecting events there is also a reasoning capability based on correlation algorithms that generate alerts for the anomalies detected in the events collected. Additionally, the CIPSEC framework provides with additional services, transverse to the CI monitoring activity, which complements the activities carried out:

- vulnerability tests and recommendations, including cascading effect attacks; which allows to have a snapshot of the level of protection against cyber threats exploiting current vulnerabilities of the assets within a CI ;
- security information sharing, leveraging the report of security incidents either across the infrastructure or to the rest of the world, in order to, for instance, prevent incidents propagation;
- training services, assisting on the usage of the framework and on different characteristics of security management aspects, allowing for an easy training of security staff in the context of the CIPSEC framework;
- updating and patching mechanisms, with the purpose of having a unified view of the status of all the monitoring tools deployed in the infrastructure and giving the possibility to automatically update them, guaranteeing the timely protection against the latest security threats.

The CIPSEC framework is being validated in real environments using the infrastructure of three pilots that covers different domains: rail transportation, environmental monitoring and health sector.

CIPSEC architecture

For the sake of flexibility, the CIPSEC framework was designed to be independent from the underlying critical infrastructure (i.e., independent from the resources managed or the security requirements). The reference architecture of CIPSEC was conceived based on the flow of the data managed within a CI, or, said otherwise, was design to be infrastructure-agnostic by design. With this aim, the architecture is defined according to the life cycle of the security data (logs, events, reports) acquired, disseminated and consumed in CIs.

Data Acquisition refers to the process of collecting or storing the information (logs, events) generated by end devices devoted to secure the integrity of CIs. Thus, there are multiple sources of this data, e.g., intrusion detection systems.

Data Dissemination covers the transmission of the acquired security information to the components that will further process it. The dissemination of this data is usually performed in real-time describing the multiple processes carrying out in a CI, so that they can be monitored and controlled. In the context of CIPSEC, the information disseminated encompasses security data related to events, alarms, updates, etc.

Data Consumption concerns the processing of the acquired security information after being disseminated to the relevant consumers (e.g., incident correlators). Such information is processed and interpreted to fuel several assessment tools that enable users to make informed decisions.

Figure 1 depicts the architecture of the CIPSEC framework based on a group of layers that follow the flow of security data described above. This illustration also shows how the security data travels from the CI to a user interface so that the system admin can take appropriate decisions based in the processing activities carried out by the framework, such as enforcing mitigations or applying contingency plans.

The acquisition layer obtains a lot of information directly from the CI components dedicated such as vulnerability assessment, identity access management, integrity management, endpoint detection and response, and cryptography. The information collected is aggregated and processed by a component called anomaly detection reasoner that triggers security alerts depending on the patterns devised in security data.

The *data processing* layer is on top of the acquisition layer and involves two main components: the DPT and the forensics service. While the forensics filters and analyzes indicators potentially useful for forensic analysis, the DPT aims at preserving privacy in the security data coming from the CI and at storing such sanitized data in a different database for sharing purposes. This component is the one whose implementation we present in this paper.

The *presentation layer* aggregates the information produced by the underlying layers through a dashboard that offers a user interface where statistics and evolution indicators are presented to illustrate the security status of the whole CI. Such interface provides with an aggregated and uniform view of this status to the user in order to facilitate decision-making processes.

Finally, other complementary services are also provided by the architecture in order to guarantee the support to end users, the compliance with the CIPSEC framework, and the continuity of the services.

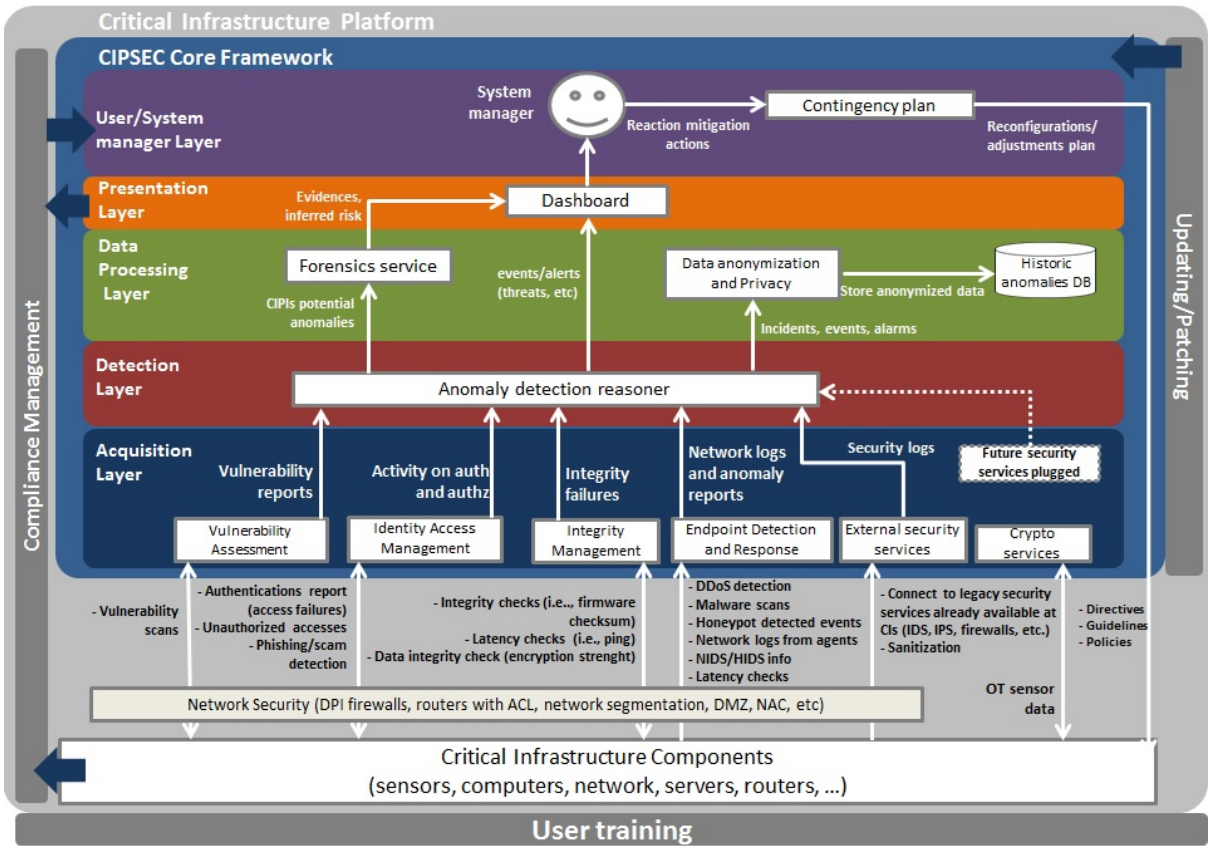


Figure 1. CIPSEC Reference Architecture for protecting of critical infrastructures.

DATA PRIVACY TOOL

Background on cybersecurity logs and privacy protection mechanisms

Logs are pieces of information that sequentially register the events affecting a system; therefore, when seen aggregated, they constitute evidence of the system behavior. Said diagnosis is fundamental to scrutinize and then fix a given issue, even more in the cybersecurity realm where thousands of attackers are permanently generating incidents that threaten the integrity of critical systems connected to the Internet.

Usually, logs contain a lot of granular information on the related event, starting with a time stamp. Cybersecurity logs may include, e.g., IP addresses, process IDs, hardware information and event descriptions.This information is stored in text files formatted to guarantee its agile reading and processing. For instance, two formats extensively used to store logs are XML and JSON. Both have interesting features based on labels to present information as name-value pairs, e.g., "ID: 123456" or "Alarm type: critical". Namely, the attributes or information elements of a log are organized using a name (or label) of the attribute and its corresponding value (the raw data). This way of representing information in logs significantly facilitates further selection and replacement (transform) of sensitive attributes.

Roughly speaking, protecting said information against privacy threats builds on these two operations: *selection* of sensitive attributes in the logs and *transformation* of corresponding values to a more private version. This is more deeply described in this document, where our proposal is presented. Although the definition of said operations depend on the context (sharing policies, organization concerns, etc.), the modern ways to structure logs are decreasing the complexity of performing these operations of selection (search) and transform (replace).

First, to protect privacy, sensitive attributes (the target) must be defined and then detected in logs. In practice, this task consists in searching for specific information in plain text. Given the vast log data that cybersecurity systems could generate, such searching for specific items might be daunting if it is expected to be done manually by a human operator. Fortunately, technology can now be used to automatize the detection of this type of attributes. Moreover, the most common logging formats are based on labeling every single piece of information contained in the log. Thus, once the sensitive attribute (or its label) is defined, it is not difficult to retrieve it from the logs along with its value. If the data within logs were not appropriately formatted, sensitive information should be located by looking

for specific syntax patterns that such information present in logs. For instance, if IP addresses were considered as sensitive information, the privacy protecting approach could start detecting IP addresses in logs by resorting to its unambiguous syntax. Then, searching for a pattern of four numbers separated by dots would eventually lead the system to find said IP addresses. Regular expressions are powerful constructions that can be used to represent and search such patterns.

After finding the attribute in cybersecurity logs, it has to be protected to preserve the privacy of involved companies or individuals. This implies modifying or transforming the value of the attribute to obfuscate any sensitive information there contained. This task is also referred to as *sanitization* in the sense that it "cleans" data from too distinctive attributes. To do so, some anonymization or sanitization mechanisms are commonly implemented. These mechanisms are described in the following lines.

Suppression is the simplest strategy to protect privacy in this context. It consists in completely eliminating sensitive information, which can be interpreted as replacing it for a blank or any meaningless string. This implies that no trace of said sensitive data is left which may directly affect the utility of the logs.

Generalization is rather a less destructive anonymization approach. It builds on replacing sensitive information with more general but still meaningful data. For instance, if the sensitive piece of data is the IP address 192.168.1.1, a generalized version would be 192.168.0.0. In contrast with suppression, generalization could keep some utility from the data in log records, depending on the deep of generalization attained.

Pseudonymization is a mechanism that consists in replacing identifying information by artificial identifiers, also called pseudonymous. Since said pseudonymous would be used instead of the original identifier, each time the latter appears, it is possible in practice to recover the original information from its pseudonymized version. Also, if such identifiers are only used for identifying purposes, pseudonymizing them would not affect the utility of information.

As briefly described, the resulting utility of cybersecurity logs may be more or less affected depending on the anonymization mechanism used to protect privacy.

Privacy risks from disclosing cybersecurity logs

In general, logs contain a lot of information since they are aimed at describing the state of a system at a given point in time. Further, an aggregated set of logs should enable an administrator to have a general view of the performance of said system. In particular, the specific amount of data items (we will call them attributes) present in a log record will depend on the level of granularity set in the logging service. Interestingly, some equipment, e.g., networking devices, allow to be configured with such high levels of granularity that manufacturers explicitly warn about the risk of saturating storage or processing resources. Thus, logs could become extremely detailed pieces of data describing a system where companies and individuals are involved.

Cybersecurity logs might include very sensitive data since they are commonly associated with vulnerabilities and security threats. If that information fell into the wrong hands, it could cause severe damage to the data owners. Besides, the level of granularity of security logs is usually higher to afterwards enable the detection of security breaches (which use to be provoked by undercover interactions), so more and more attributes are included in logs to improve protection to the same extent. As a consequence, the potential leakage of this information implies serious privacy risks for the entities involved, not only due to the weaknesses that such logs could reveal to attackers, but also due to the increased detail of the information.

Ironically, the risk of leaking this information does not necessarily come from deliberate attacker intrusions to steal it, but from the voluntary release of such logs when sharing them to other partners. In fact, sharing cybersecurity logs has become a common practice among organizations as a collaboration mechanism to enhance the effectiveness in detecting and preventing security threats. The attributes characterizing a security incident in a system, e.g., IP addresses, file names, sizes, can be shared with system administrators with the aim to help other systems detect or prevent related threats. More specifically, information sharing enables sharing partners to enhance their defensive capabilities, i.e., detecting, responding, and recovering from cybersecurity incidents. As a matter of fact, the collective aggregation of shared security logs is currently the main input fueling powerful antivirus and network security devices.

Despite the great benefits that sharing cybersecurity logs may bring, some challenges still remain. One of said challenges is safeguarding sensitive information that might be included in these logs, i.e., protecting the privacy of the entities whose information is shared. The violation of privacy in this context (e.g., due to the disclosure of personally identifiable information) may have serious consequences, particularly for companies, such as the ones listed below:

Table 1. Some attributes whose disclosure in cybersecurity logs might jeopardize privacy.

Attribute	Privacy risk
IP address	May enable identification of users and organizations.
e-mail address	May enable identification of users and organizations.
path names	Could disclose user names, directory hierarchies.
patching information	Could reveal software updating calendars, thus when
software versions	Along with other attributes, could enable fingerprinting and identification of users.
incident description	When associated with an origanization, could unveil its vulnerabilities.
organization name	May allow attackers to identify an organization.

- financial loss,
- legal action,
- loss of reputation,
- exposure to protection capabilities.

As explained above, the nature of cybersecurity information contained in logs is inherently sensitive since it includes several attributes and also some very punctual data items that may reveal strategic operations of systems regarding their security. Virtually every computing device and application are enabled to generate this type information, especially if they engage networking or Web interactions. Some examples of sensitive information that could be included in cybersecurity logs are described next.

Timestamp. A time stamp is fundamental to determine the moment when an security incident occurred. The exact date and time of the incident allow to correlate other events that could contribute on the investigation of the threat. However, if coupled, e.g., with individuals, temporal data could also help attackers perform the same correlation to unveil patterns (a person's sleep time, a company's patching calendar) to violate privacy.

IP address. IP addresses individuate devices so that security issues can be associated with the entity where the incident has been generated. Nevertheless, in the same line, IP addresses are key information for privacy attackers to identify the individuals and companies involved. In fact, an IP address could unequivocally represent an individual or a family, so the security logs related to their interactions would reveal such tight association. The mere availability of this information enables further security attacks (denial of service, fingerprinting) to companies, which could reveal even more indicators about potential victims (privacy violations).

IP addresses are not the only data items with this individuating capability. Other attributes that may appear in security logs such as user names, host names and MAC addresses have similar identification capabilities, although their presence is not as common as IP addresses. There are also apparently innocuous indicators that are contained in cybersecurity logs that can serve as identifying parameters when combined, e.g., software version and patch level information, hardware information, system event, file access, etc. Interestingly, the resulting combination of said attributes can be seen as a fingerprint of the associated entity and could be used as an identifier by itself.

Any indicator or attribute included in logs could reveal further sensitive information. The specific privacy risk, however, depends on the context, i.e., on the background information available for the attacker, and his objective, but also on the particular status of the potential victim. For example, path names could disclose information about the work a user might be performing, or operating system and patches names may reveal the preferences of a company regarding their network or software implementation (which it had been keeping secret). Disclosing such information in logs that will be shared may represent a privacy violation for users or the company whether or not the parameters included are critical for each entity.

Besides identifying attributes or other complementary indicators, the information included in cybersecurity logs may be very specific when generated by specialized devices such as routers, antivirus servers, intrusion protection systems, forensic toolkits, SIEMs (security information and event management systems), etc. Moreover, these logs contain very critical information since it is commonly derived from assessment routines, i.e., contemplates "refined data" (which in practical terms implies more and more valuable data). This information might span vulnerability alerts, system artifacts, attack alerts, or summary reports, whose disclosure is a direct threat for the privacy of the entities involved.

The risk to privacy when sharing cybersecurity logs is seriously exacerbated when CIs are involved since the corresponding entities and their workers are more exposed given the strategic role they are playing. In Table 1, we describe some attributes whose disclosure in cybersecurity logs may imply serious privacy risks.

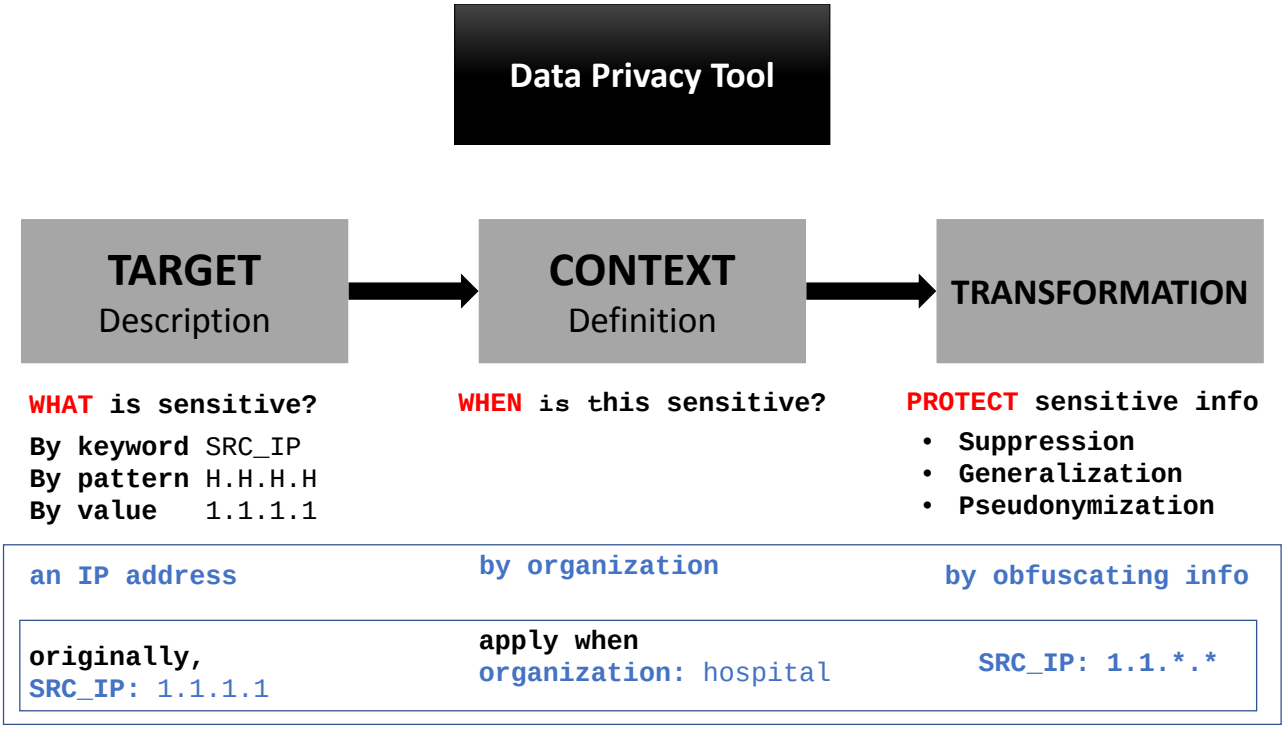


Figure 2. Architecture of the data privacy tool.

Architecture of the data privacy tool

The objective of our DPT is offering privacy for individuals and institutions in a context where cybersecurity logs have to be shared among different partners. While disclosing and aggregating such data may improve the capabilities of security solutions in CIs, the high granularity of logs and the sensitive attributes there contained may jeopardize privacy. Thus, we devise a tool to protect this sensitive data by anonymizing it. This tool encompasses the components described below.

Target description

The first step in protecting privacy in cybersecurity logs is determining the set of sensitive attributes that will have to be sanitized. Said otherwise, the specific target of the anonymization mechanisms has to be defined since logs use to hold a lot of information.

The level of sensitivity, however, depends on the specific context in which users and companies perform (their interests, needs, worries, adversaries, etc.). Moreover, although some attributes might be defined as sensitive by default (e.g., identity numbers), or automatic mechanisms could be created to "recognize" them, the operators of the DPT should always have the last word when deciding what attributes to protect by defining a privacy policy.

Evidently then, to locate sensitive attributes and their values within the data provided by logs, some language might be necessary for the user to describe the corresponding targets. If logs were generated by CIs without any visible structure, patterns should be found to detect the sensitive attribute, e.g., looking for quartets of decimal numbers separated by commas to find IP addresses (which the operator would have defined as sensitive). Fortunately, to facilitate its exploitation and analysis, logs are commonly generated in structured formats, sometimes even in hierarchical trees, such that the information be organized according to certain logic and that every attribute value is labeled.

As logs are presented through standard approaches and attribute values are indexed through labels, it is straightforward to refer to such attributes to then retrieve their values. For instance, let us suppose that the operator is interested in preventing individuation of his company in the logs generated by their devices. Thus, he might have to detect identifying data in logs, such as IP addresses, to anonymize them and protect privacy. There may be different approaches to search for IP addresses in a log, as described below.

- **By keyword.** Within cybersecurity logs, IP addresses are usually labeled with a keyword such as SRC_IP (source IP) or DST_IP (destination IP) or any other. Knowing such keyword, it is pretty easy to obtain the sensitive value associated in the corresponding log.

```
{'AlarmEvent': {
'USERNAME': '', 'SRC_IP': '188.112.63.117', 'BACKLOG_ID':
'839301cfd5b54179847535ffa3e29adc', 'DATE': '2018-07-17
09:00:16',
'DST_IP': '84.88.67.117', 'USERDATA7': '', 'USERDATA6': '',
'FILENAME': '', 'PRIORITY': 4, 'RELIABILITY': 10,
'ORGANIZATION': 'hospital', 'SENSOR':
'AD14C6F3975ED9860E32190EA3DF2535', 'SID_NAME':
'directive_event: Detected access to SAMBA in Honeypot',
'USERDATA2': '', 'USERDATA3': '', 'USERDATA1': 'tcp',
'PROTOCOL': 6, 'RISK': 4, 'USERDATA4': '', 'USERDATA5': '',
'EVENT_ID': '04447d36c0614e3fbe70b5b4612adf2e', 'USERDATA8':
'', 'USERDATA9': '', 'PLUGIN_NAME': 'cyber-monitor',
'DST_IP_HOSTNAME': '00000000', 'RELATED_EVENTS':
'[899f11e885a4080027ea052cd289c2dc,899f11e885a4080027ea052cd2
b27c90]', 'PASSWORD': '', 'PLUGIN_SID': '2', 'CATEGORY':
'Recon', 'SRC_IP_HOSTNAME': '00000000', 'SUBCATEGORY':
'Scanner'}
```


Figure 3. Sample of logs generated by the CIPSEC framework.

- **By pattern.** If the sensitive data to be anonymized is not systematically associated with an index or label, a pattern could be used to look for such data. In the IP address example, e.g., we could look for any group of four numbers from 0 to 255 separated by dots, which could be symbolically represented as X.X.X.X.
- **By value.** Still in the case when no specific keyword is available, the value of the sensitive attribute could be directly searched in the logs. The drawback of this approach is evidently that this search spans a single value while the firs two may encompass a wider spectrum of values.

Since the first step to protect privacy in cybersecurity logs involves searching for a string (keyword, pattern or value) in a piece of text, it is worth noting that, at an implementation level, the use of regular expressions is highly recommended for such tasks. See Figure 2 where this component of target description of our DPT is depicted as it would work with the other two components described in the next subsections.

Context definition

As stated in the previous section, the sensitivity of some data item is subject to the context where its owner performs. In the same line, the privacy protection mechanism required will vary according to the specific needs and characteristics of the subjects involved. The context-definition component then enables the user of our DPT to set any restriction or condition on the application of the privacy protection strategy.

While a lot of restrictions could be integrated, there is one in which we are interested for the CIPSEC framework. Since three different pilots or organizations are sharing their cybersecurity logs, the user of the DPT could opt for anonymization or not depending on the organization he belongs to. For instance, air quality monitoring might not involve sensitive attributes for the organization generating such data so could decide not anonymizing their data. Other more complex scenarios may be characterized, e.g., by a company having very specific needs on anonymizing attributes that in other contexts might not be critical to protect. In brief, the scope in which our DTP is used may also define the operation of the DPT.

In Figure 2, we illustrate this component within the whole architecture of this tool.

Transformation

Once sensitive information and context are defined, sensitive data has to be transformed in order to protect privacy. Said transformation implies perturbing attribute values so that, e.g., identifiers no longer serve to identify individuals, or that sensitive values provide less specific information regarding individuals or companies.

The transformation component in the architecture of our DPT is implemented through the anonymization mechanisms described in Section 3.1. As explained above, such mechanisms will replace the original sensitive value with another (at least less specific) string. Figure 2 shows how this component is integrated in the architecture of our DPT.

It is worth noting that when transformation has to be done dynamically (i.e., when replacing according to a a predefined pattern), regular expressions are also very useful as with target description.

```
"SRCIP":{
      "ORGANIZATION":"all",
      "ACTION":"generalization",
      "TYPE":"ip_address",
      "KRE":"^SRC_IP$",
      "VRE":"",
      "SRE":""
},
"USERDATA":{
         "ORGANIZATION":"all",
         "ACTION":"suppression",
         "KRE":"^USERDATA*",
          "VRE":"",
         "SRE":""
},
```

```
"ORG":{

      "ORGANIZATION":"hospital",
      "ACTION":"pseudonymization",
      "TYPE":"organization",
       "KRE":"^ORGANIZATION$",
      "VRE":"",
      "SRE":""
 }
```

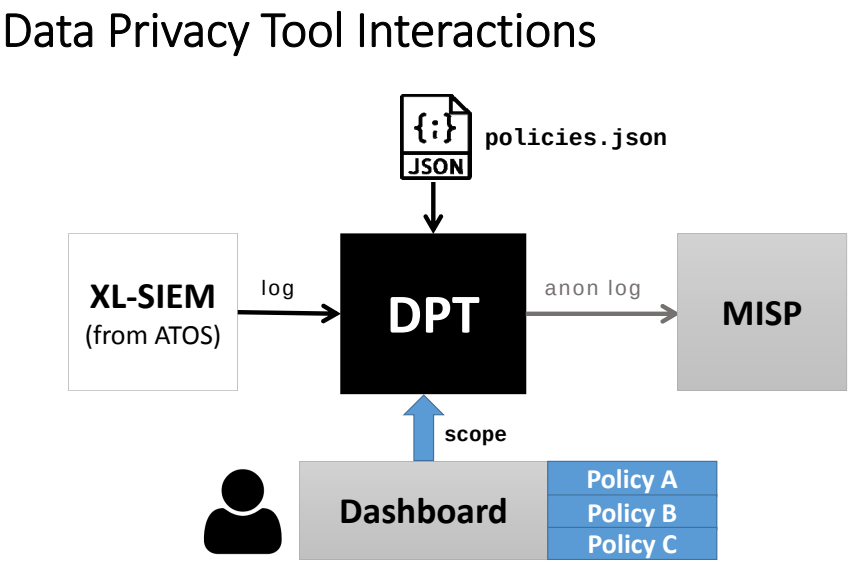


Figure 5. Interactions of the DPT with different components of the CIPSEC framework.

Privacy policies

In order to enable users to set the context of their privacy protection, a privacy policy has to be defined. A privacy policy is essentially a list of named rules that include the parameters that characterize the anonymization of sensitive information, i.e., the description of the specific attribute to be anonymized, the transformation mechanism to use, and any other criterion (e.g., the organization whose logs will be anonymized).

IMPLEMENTATION AND INTEGRATION IN THE CIPSEC FRAMEWORK

As explained throughout this article, cybersecurity logs enable the intelligent protection provided by the CIPSEC framework. Meanwhile, our DPT aims at preserving the privacy of individuals and organizations involved in such logs when shared among different partners. All the logs generated by several security devices in the CIPSEC infrastructure are aggregated and formatted in standard JSON format in real time to then be stored in a security information and event management server (XL-SIEM). Figure 3 depicts a sample of these logs that are further available for sharing in a Malware Information Sharing Platform (MISP).

As mentioned in Section 3, our DPT has three main inputs that guide the anonymization process: the cybersecurity logs that are fueled by the XL-SIEM; a privacy policy, also as a file formatted in JSON (an example is depicted in Figure 4); and a scope that indicates the organization that is executing the anonymization process. The latter

argument enables the user to anonymize only the logs that belong to his organization. After logs are anonymized, they are sent to the MISP for sharing purposes.

Finally, for the sake of usability, the control of the execution of the DPT and the selection of the privacy policy is delegated to a graphical user interface integrated in the dashboard of the CIPSEC framework. Figure 5 illustrates the components mentioned in this section and their corresponding interactions, while Figure 6 shows how a single anonymized log record would look. As a side note, our DPT is implemented using Python.

Related work

The concerns on the privacy risks from cybersecurity data are not new. The Government Accountability Office (GAO) of the USA already reports in (*High risk series: An update. Ensuring the security of federal information systems and cyber critical infrastructure and protecting the privacy of personally identifiable information* 2015) how the advances in technology have given rise to important challenges to ensure the privacy of personally identifiable information. The GAO recommends implementing privacy practices to protect personal identifying information, especially when managed in critical infrastructures. But in a wider scope, severe regulation is currently been applied in the USA and Europe (*General Data Protection Regulation (GDPR)* 2016) to protect privacy at every context, essentially by given users great control over their data. Though these documents acknowledge the increasing need to protect privacy, they are regulatory approaches that require implementation according to the specific domain.

Several approaches can be found in the literature that describe privacy preserving mechanisms on unstructured data (e.g., any type of log data). Those mechanisms are based on sanitization (through suppression, generalization, or any kind of perturbation) of such data. Some works address related mechanisms (Sánchez and Batet 2015), not only focused on protecting privacy but also on preserving the utility of sanitized data (Sánchez, Batet, and Viejo 2014). Interestingly, some of such approaches even consider the semantics of the text to be sanitized to get more efficient mechanisms (Sánchez, Batet, and Viejo 2013; Chakaravarthy et al. 2008). Unlike those works, our approach focuses on privacy preserving within cybersecurity data in the particular context of the CIPSEC framework.

With regards to the exchange of threat information several initiatives are exploiting their possibilities. For example, the DiSIEM project [1] uses it to empower Security Information and Event Management systems by exporting and importing data about incidents detected, allowing for the update of detection rules according to the information imported. DiSIEM also uses MISP as platform for the exchange of information although the privacy considerations are something not considered so far. Also, in 5G networks it is considered the usage of Threat Intelligence Exchange capabilities to import and export incident information across the network slices considered in 5G infrastructures [2].

CONCLUSIONS

Cybersecurity data generated in the form of logs is very prone to including sensitive information about individuals and organizations, even more so when such logs belong to CIs. The strategic importance of such data, then, makes those individuals and organizations common targets of privacy adversaries. The EU project CIPSEC integrates the cybersecurity information systems of three CIs to improve their threat detection and reaction capabilities. However, since this integration involves sharing such cybersecurity data, there are privacy risks that must be tackled.

The solution we propose addresses this issue by pre-processing logs to anonymize sensitive attributes according to a privacy policy that defines a particular context. Enabling users to set privacy policies is definitely the most important and complicated task since many factors have to be considered to define not only what data to anonymize, but also when and how. Fortunately, the logs generated by information systems are currently represented using more structured and flexible formats (e.g., JSON), which, along with the power of regular expressions to define context, significantly facilitate matching and dynamically perturbing string-based attributes.

As a work in progress, there are several avenues to enhance our privacy tool. Perhaps the most important pending work has to do with assessing the impact of the anonymization mechanisms on the practical utility of cybersecurity logs. Undoubtedly, data perturbing strategies reduce the quality of of the information involved so a balance must be reached to protect privacy while minimizing utility loss. Moreover, standardization of the definition of privacy policies is necessary to simplify the configuration of the anonymization mechanisms. This could be a daunting task so automating it according to the requirements of users and organizations might certainly help. Furthermore, a challenge in data sanitization is the reidentification risk posed by inferences based on several attributes exploited simultaneously. Finally, in the same line, more usable (probably graphical) interfaces could be developed to enable end users to provide the parameters of a personalized context in order to better guide the anonymization process of cybersecurity logs.

[1] DiSIEM project web page: http://disiem-project.eu/

[2] D3.1. Initial resilience and security analysis: http://5g-monarch.eu/wp-content/uploads/2018/06/5G-MoNArch_761445_D3.1_Initial_resilience_and_security_analysis_v1.0.pdf

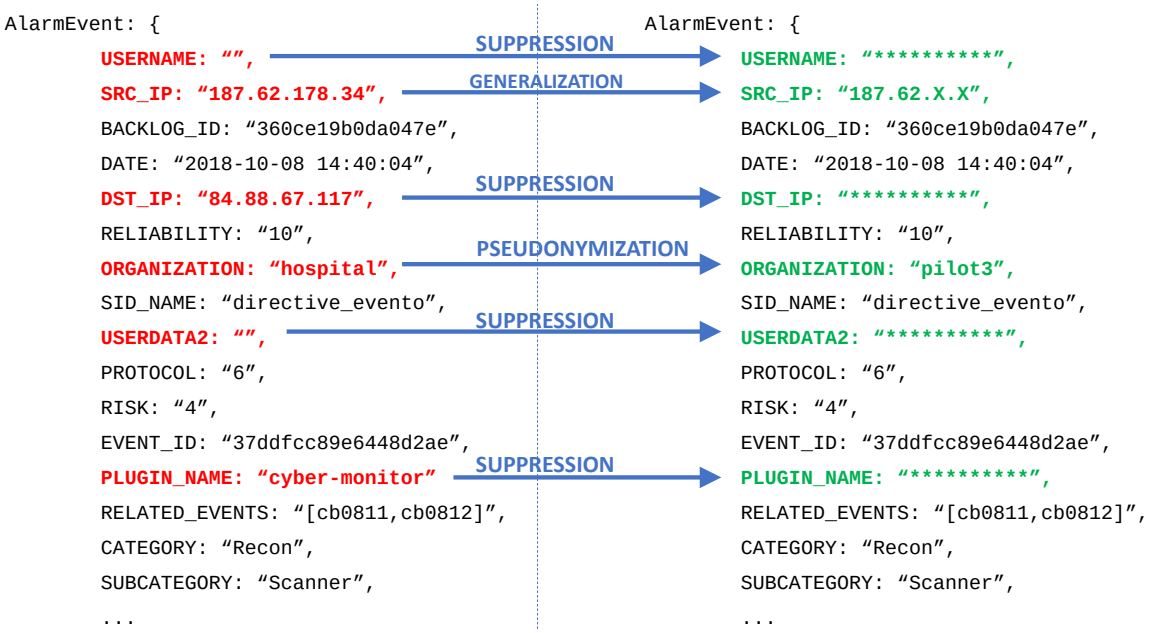


Figure 6. A view on how the privacy in cybersecurity logs could be protected through different anonymization mechanisms.

ACKNOWLEDGMENT

The authors gratefully ackowledge the support of Ahmad Mohamad Mezher for this contribution. This work has been funded by the European Commission through the H2020 project "CIPSEC", grant agreement 700378. Aditional support has been obtained from the Spanish Ministry of Economy and Competitiveness (MINECO) through the projects "INRISCO", ref. TEC2014-54335-C4-1-R, and "MAGOS", ref. TEC2017-84197-C4-3-R.

REFERENCES

Chakaravarthy, V. T., Gupta, H., Roy, P., and Mohania, M. K. (Oct. 2008). "Efficient techniques for document sanitization". In: *Proc. ACM Int. Conf. Inform., Knowl. Mgmt. (CIKM)*. Napa Valley, CA, pp. 843–852.

Edwards, J. (2018). "Someone is trying to take entire countries offline and cybersecurity experts say ítś a matter of time because 'it's really easy'". In:

High risk series: An update. Ensuring the security of federal information systems and cyber critical infrastructure and protecting the privacy of personally identifiable information (Feb. 2015). Rep. Congr. Cmte. GAO-15-290. U.S. Gov. Account. Office (GAO), pp. 235–254.

General Data Protection Regulation (GDPR) (Apr. 2016). Regul. (EU) 2016/679, Eur. Parliam.

House, T. W. (Feb. 2013). "Presidential Policy Directive – Critical Infrastructure Security and Resilience". In:

Moyer, E. (Sept. 2010). "Stuxnet worm hits Iranian nuclear plant". In: *https://www.cnet.com/news/stuxnet-worm-hits-iranian-nuclear-plant/*.

Sánchez, D. and Batet, M. (Apr. 2015). "C-Sanitized: A privacy model for document redaction and sanitization". In: *J. Assoc. Inform. Sci., Technol.* 67.1, pp. 148–163.

Sánchez, D., Batet, M., and Viejo, A. (Nov. 2013). "Minimizing the disclosure risk of semantic correlations in document sanitization". In: *Inform. Sci.* 249, pp. 110–123.

Sánchez, D., Batet, M., and Viejo, A. (Sept. 2014). "Utility-preserving sanitization of semantically correlated terms in textual documents". In: *Inform. Sci.* 279, pp. 77–93.

Swinford, S. (Apr. 2018). "Russia preparing to mount cyber-attack on Britain's 'critical infrastructure', GCHQ and FBI warn". In: *https://www.telegraph.co.uk/politics/2018/04/16/russia-preparing-mount-cyber-attack-britains-critical-infrastructure/*.

Woollaston, V. (May 2017). "Wanna Decryptor ransomware appears to be spawning and this time it may not have a kill switch". In: *https://www.wired.co.uk/article/wanna-decryptor-ransomware*.

Track 14.

Protecting Critical Infrastructures in Crisis Situations

Chairs,

Stefan Schauer, *Austrian Institute of Technology*

Stefan Rass, *Alpen-Adria-Universität Klagenfurt*

Evaluating Critical Infrastructure Resilience via Tolerance Triangles: Hungarian Highway pilot case study

Laura Petersen
Centre National de la Recherche Scientifique (CNRS)
&
The Worldwide Railway Organisation (UIC)
laura.petersen1@gmail.com

Johan Sjöström
Research Institutes of Sweden (RISE)
johan.sjostrom@ri.se

Eva Horvath
Magyar Közút Nonprofit Zrt.
horvath.eva@kozut.hu

ABSTRACT

While accepted as part of critical infrastructure (CI) resilience, no consensus exists on how to measure the exact minimum level of service or the rapidity of rapidly restoring services. The H2020 European project IMPROVER (Improved risk evaluation and implementation of resilience concepts to critical infrastructure) suggests to use the public's declared tolerance levels for both minimum level of service and rapidity of service restoration as criteria with which to evaluate if the resilience of a given CI is resilient enough. This paper demonstrates the development of a questionnaire-based methodology to determine public tolerance levels. It then tests this methodology via a pilot case study at IMPROVER's Hungarian Highway Living Lab. The paper argues that public tolerance levels are a reasonable choice for resilience evaluation criteria and demonstrates that the questionnaire-based methodology permits one to evaluate public perception in such a way as to compare it to technical resilience analyses.

Keywords

Critical infrastructure, resilience, questionnaires, tolerance triangle.

INTRODUCTION

Critical infrastructure (CI) resilience is defined by the H2020 European project IMPROVER (Improved risk evaluation and implementation of resilience concepts to critical infrastructure) as: "the ability of a CI system exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, for the preservation and restoration of essential societal services," which is adopted from the UNISDR (United Nations International Strategy for Disaster Reduction) definition. Thus, key parameters associated with CI resilience are both the ability to maintain a minimum acceptable level of service and the ability to rapidly restore full service in relation to a crisis event on the CI system. However, no consensus currently exists on how to measure these elements. Furthermore, once measured, how does one know if one's CI is resilient enough?

To answer these questions, IMPROVER has designed a framework: IMPROVER Critical Infrastructure Resilience Framework (ICI-REF), which proposes a relationship between CI resilience and CI risk assessment (Figure 1) (Lange et al., 2017). ICI-REF maps resilience management onto common risk management frameworks (such as ISO 31000). Within this framework, *resilience assessment* is made up of both *resilience analysis*, where the given level of resilience which a CI has (in response to an identified threat and within a given resilience domain if appropriate) is identified, and then *resilience evaluation* whereby the results of the *resilience analysis* are compared with some criteria to determine if the resilience is adequate or if further action is required to improve it.

The IMPROVER project has suggested to use the public's declared coping capacity as criteria for *resilience evaluation*. Indeed, previous work within the IMPROVER project has found that the general public, end users of CI services, appear to have reasonable expectations of CI operators in crisis times (Petersen et al., 2017a; Petersen et al., 2017b; Petersen et al., 2018a). The public's reputation for having too high of expectations appears unmerited; they are willing to cope in times of crisis. Further, this better aligns the idea of resilience to the purpose of CI, namely to deliver services to society. As an added bonus for CI operators, going beyond meeting needs to meeting expectations helps maintain reputation during a crisis (Barker, 2013).

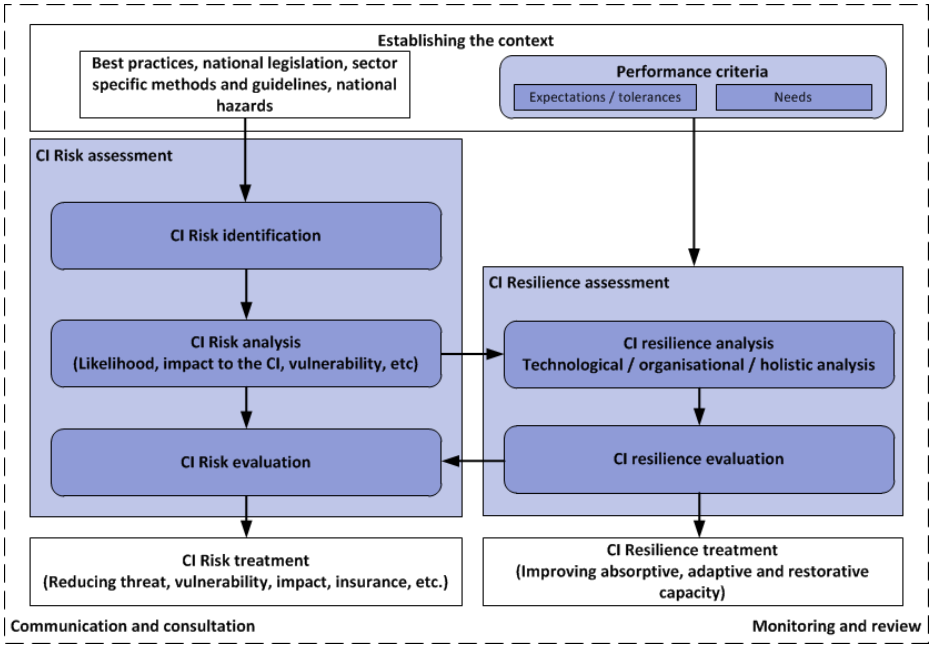


Figure 1 IMPROVER ICI-REF. CI operator risk and resilience management process (note that 'Communication and consultation' and 'Monitoring and review' are continuous processes which should interact with all other processes)

We propose to use a questionnaire survey in order to determine the public's perception of their own coping capacity in crisis times. Previous research has shown that people are good judges of their ability to deal with disturbance and change (Nguyen & James, 2013). The idea of people being able to accurately judge themselves has been used successfully in psychology, well-being and subjective resilience domains (Jones & Tanner, 2015). Furthermore, previous research into customer preferences and satisfaction has also used questionnaires to establish coping capacity in times of reduced service (OECD, 2001; Centre for Transport & Society, 2015; Transport Focus, 2017). The goal of the questionnaire then is to have a comprehensive understanding of the local population's expectations and tolerance levels. It is important to remember that it is the public's own views that are of interest here. While, as seen in Figure 1, within ICI-REF understanding the tolerances of the population falls under *establishing the context*, it is necessary that the questionnaire is designed in such a way that the results will be comparable to the results of the *resilience analysis* during the *resilience evaluation* part of the framework.

Within the IMPROVER project, a pilot test of such a questionnaire for a highway infrastructure was carried out. Similar work was carried out for a municipal freshwater network (Petersen et al., 2018b).

Public expectations for highways in crisis times

The relative importance of transportation infrastructure in ensuring emergency response, providing accessibility to other critical infrastructures for their recovery and in the day-to-day lives of citizens explains the high expectations for transportation infrastructure during and after a disaster (Petersen et al., 2017b). There is an expectation that a minimum level of mobility can be achieved, even if that requires a change in means of getting around (Petersen et al., 2018). Previous research has shown that the public is willing to tolerate reduced transportation service in terms of reduced capacity or frequency, diversion or alternative means for a period of months (Petersen et al., 2018). Recent research into public tolerance levels to a change in service of the Oresund Crossing due to the refugee crisis in 2016 using both questionnaires and a case study found that the public was willing to tolerate service disruption in times of crisis (Petersen et al., 2017a). Another recent study of the Oresund Crossing asked users "do you have a plan B?" in the case of service disruption and found that respondents felt capable of coping with short, medium, and long-term disruption scenarios (Dahlberg, 2017). When highways are

no longer operable due to a crisis, the public appear to expect an offer of public transporation to be made available based on survey results from victims of both the 2011 Great East Japan Earthquake and the 2010-11 Queensland Floods (Regional Australia Institute, 2013; Nakanishi et al., 2014).

However most previous research into public expectations/tolerances/satisfaction of transportation infrastructure does not investigate crisis times but instead "normal" times or planned works. Much research in this area has focused on user satisfaction with roadways by evaluating travel time, reliability of travel time, and delays in travel time (OECD, 2001). Unsurprisingly, the greater the delay experienced by the user, the worse the impact is on user satisfaction (Centre for Transport & Society, 2015). However, satisfaction surveys also demonstrate that the cause of the delay affects expectations, whereby accidents and "unexplained incidents" are mainly accepted by users as unforeseen events (Transport Focus, 2017), further demonstrating that people are willing to adapt after a crisis. Lastly, once a delay is communicated to the users, users are willing to accept it as part of their normal mobility, meaning that there is not a reduction in satisfaction due to the stated delay (Centre for Transport & Society, 2015; Transport Focus, 2017).

Hungarian M1 Highway Living Lab

The IMPROVER project uses Living Labs in order to study various aspects of CI resilience. Living Labs are a research concept that create an open-innovation ecosystem and use a systematic user co-creation process. This means the actors of a Living Lab are not simply subjects but also active participants in the research process. Thus, qualitative methods such as semi-structured interviews are carried out with the actors of the Living Lab. Living Labs have been the focal point of the scientific work carried out within IMPROVER and have been used to test various project methodologies, including the creation and implementation of tolerance questionnaires.

The M1 Highway is one of the most important highways in Hungary, serving the north-west part of the country (Figure 2). It is a transport infrastructure of importance at both national and European scale as it provides passenger and freight transport between the country's capital, Budapest, and two neighbouring capital cities: Vienna in Austria and Bratislava in Slovakia. The M1 highway is operated and maintained by Magyar Közút Nonprofit Zrt. (Hungarian Public Road Non-Profit Plc. - Közút). They were established in 2005, starting in 2014 were owned by the Ministry of National Development and since 2018 are owned by the Ministry for Innovation and Technology.

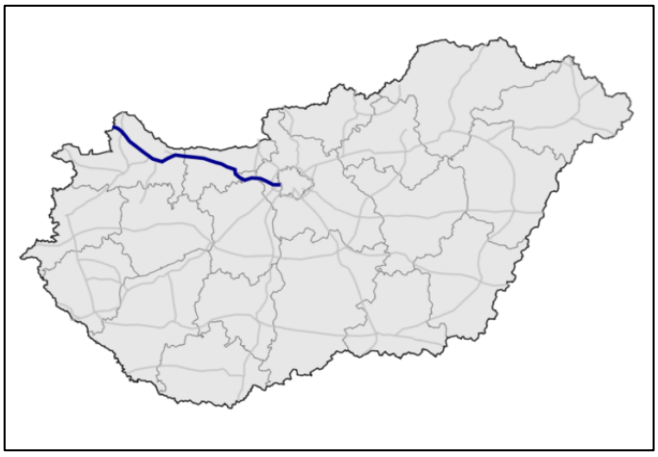


Figure 2 The IMPROVER Living Lab of the M1 Hungarian Highway shown in blue on the map

Several hazards may influence the highway network, including snowstorm, earthquake, flooding and collision leading to serious damage of bridges. A recent snowstorm that impacted travel on the M1 highway occurred on March 14, 2013 leading to a 3-day closure, where trucks were stuck, traffic was diverted to Road 1, the army had to intervene and evacuate cars, and which affected a total of 17,000 people. The effects of the crisis were heightened due to the combination of the storm occurring the day before a major Hungarian holiday, leading to an already increased rate of road traffic, and a swift change from spring-like weather to a winter storm. Another recent crisis event occurred on 19th May 2010 when flooding led to a 2-day closure of the M1 Highway, causing major traffic disruption, including cross-border traffic to and from Austria. The tender for restoration amounted to a total of 100 million HUF (ca. 437.000 USD at the time of the incident). (Honfi et al., 2018)

METHODOLOGY

Establishing the context

As stated in the introduction, if the results of the assessment of public expectations are incompatible with the resilience analysis, it will be difficult to use them as criteria for resilience evaluation. Thus, public perception of their own coping capacity in crisis times must be obtained in a way that is comparable to the technical performance measures of the service in question. In addition, the defined functionality and ways of measuring performance need to reflect one another. Within the IMPROVER project a resilience analysis using the IMPROVER Technical Resilience Analysis (ITRA) methodology is defined (Honfi et al., 2017). ITRA is currently being applied to the Hungarian M1 Highway Living Lab, however outside the scope of this paper. Through interviews with the living lab, it was discovered that highway performance is considered normal if, on the considered section, the highway is fully open for traffic and traffic flow is continuous without queuing. In such a case, the traffic demand is less than the actual capacity of the highway. As such, the main function of the M1 highway used for these studies was defined as being able to provide undisrupted traffic of passengers and goods, while ensuring user safety. The performance measure then to study this functionality was the travel time between selected origin destination pairs. Questions then were asked about the applicable performance measures of additional journey time and duration of additional journey time. Other factors influencing tolerance levels such as alternative routes and information provision were taken into account by inclusion in the detailed scenario (see below). In order to develop the questionnaire with a view to real world performance capabilities of operators, a combination of desk research and semi-structured interviews with the living lab operators were used.

The questionnaire was designed as an online questionnaire. The target population was adults aged 18+ who are users the M1 Highway, excluding professional users (i.e. lorry drivers). Convenience sampling was used. The questionnaire was registered with CNIL (French authority for digital privacy) and reviewed by the project's Ethics Officer. Respondents were informed of their right to withdraw from the project at any time and that the anonymised data from the questionnaire could be used in publications, presentations and reports. The questionnaire was published in English and Hungarian to best meet the linguistic needs of the user population. Unfortunately, despite the highly international character of the highway, researchers were unable to translate the questionnaire into German or Slovak. Data collection was held between 24 April 2018 and 10 June 2018.

The questionnaire began by asking respondents about their typical M1 highway usage and also investigated disaster preparedness, risk awareness and previous disaster experience of respondents. This is because expectations have been found to be influenced by these factors (Petersen et al., 2018).

Technological resilience is typically hazard dependent, having a strong link to risk analysis. Thus, in order for the results of the questionnaire to be comparable, the same hazard scenarios were considered here. Although the hazard assessment identified several potential scenarios, the two chosen for further study were a collision and a severe snow storm. These were chosen based on the interest of the operators via interviews. The collision scenario was important to Magyar Közút as they are responsible for the management of the Hungarian bridge stock, and the severe snow storm scenario was of great interest following the 2013 snowstorm crisis.

The following are the detailed scenarios that were presented individually to the respondents:

- Scenario 1: Imagine that a crash causes serious damage to a bridge on the M1 highway, leading to the closure of part of the M1 highway and prolonged delays. Users of the road will need to use deviations and will be informed ahead of time about increased travel times.
- Scenario 2: Now imagine that a heavy snow storm occurs in Budapest. Weather forecasting has predicted that there will be enough snow to impact traffic flows. Residents have been encouraged by local authorities to seek shelter and avoid traveling during the storm. Highway Operator crews have prepared the roads with salt and have used snowplows to keep the roads clear for as long as possible. However, now the M1 highway is no longer open, leading to prolonged delays.

After the presentation of a given scenario, the following two questions were asked. The first question was, "After [Scenario 1 or Scenario 2], how much additional journey time are you willing to tolerate when using a personal vehicle on the deviation route when travelling for…? Commute to work; Leisure (shopping, running errands); Holidays; Business trips." The times provided were: <20 minutes; 20 – 29 minutes; 30 – 44 minutes; 45 – 59 minutes; > 1 hour. This question aimed to capture the minimum level of acceptable service in regards to additional journey time.

The second question dealt with the duration for which an additional journey time would be tolerable. It asked, "After [Scenario 1 or Scenario 2], for how long would you be willing to put up with an additional journey time of…?" The time frames presented for the total crisis duration were different depending on the scenario. Based on the interview with Közút, the questionnaire recovery range for the collision (scenario 1) was proposed to be from less than 1 day to more than 1 month. The rather lengthy recovery time includes the reparation of the damaged bridge to allow for a full re-opening of the roadway. The recovery times of the snowstorm were based partly on

the estimates provided by Közút, who since 2013 have increased their response-ability towards snowstorm, and partly on desk research of various recent snowstorms around the world that led to highway closure. In both cases, snowstorms appear to be cleared in a matter of days, and thus the snowstorm (scenario 2) additional journey time duration was proposed as being from 1 hour to 1 week. This question aimed to capture what the public expected in terms of "rapidity" of recovery.

Lastly, the questionnaire asked about demographic information, as culture, gender, education level and socio-economic status have also been found to influence expectations (Petersen et al., 2018). Chi-squared tests were performed to explore any significant differences across responses. For some chi-squared tests, responses were grouped together in order to have enough responses.

Dissemination Plan

Dissemination was also mostly online in both English and Hungarian. Közút showcased the questionnaire on their Facebook. They also shared it with other local authorities for them to also publicise it. IMPROVER publicised the questionnaire on their Twitter, LinkedIn, website and via their email list serve, and members of the consortium were encouraged to share it with relevant people. BME (Budapest University of Technology and Economics), the Hungarian IMPROVER partner, also published it on their Facebook and Twitter.

Figure 3 Online dissemination efforts. Right, the operator's Facebook post, Top-middle, BME's Facebook post, Bottom-middle, BME's Twitter post, Left, IMPROVER's Twitter post

Sample Characteristics

There were a total of 342 clicks on the questionnaire links (combined), which led to 116 respondents participating in the questionnaire. Filtering out respondents who had never used the M1 Highway or were professional users of the highway, in total the sample size became 68 respondents.

Due to the dissemination method, this self-selected sample was not broadly representative of the Living Lab. Sample characteristics showed that 72% of participants were male and 28% female. Most were highly educated, with 72% reporting that they have a bachelor's degree or higher qualification. Both young and old people appeared to be underrepresented in the study. Respondents aged 18-24 accounted for only 13% of the total sample and only 14% identifying themselves as aged 55 years and above. An overwhelming majority of the respondents reside in Hungary (88%), whereas around 60% of the Highway users are international users (Personal interview). Income groups were more varied (Figure 4). The majority of respondents use the M1 Highway for holiday travel (Figure 5). Due to this, a typical journal time for respondents is over one hour to two hours (Figure 6).

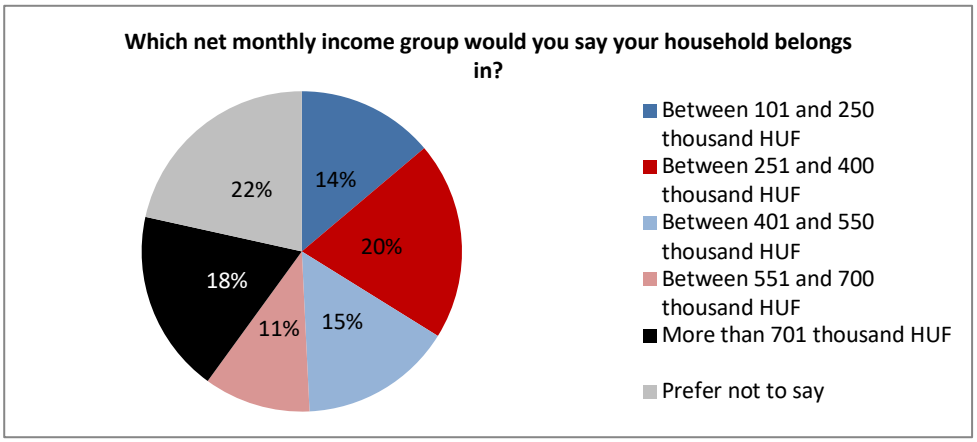


Figure 4 Monthly income group of respondents

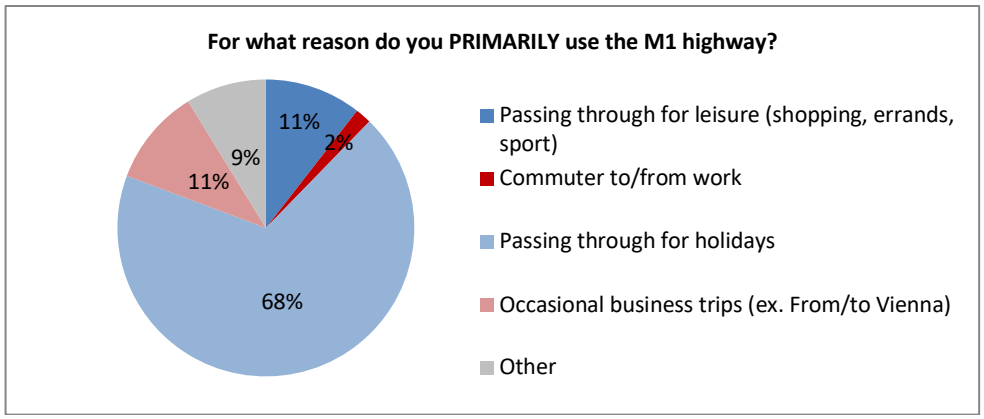


Figure 5 Respondents' primary use of the M1 Highway

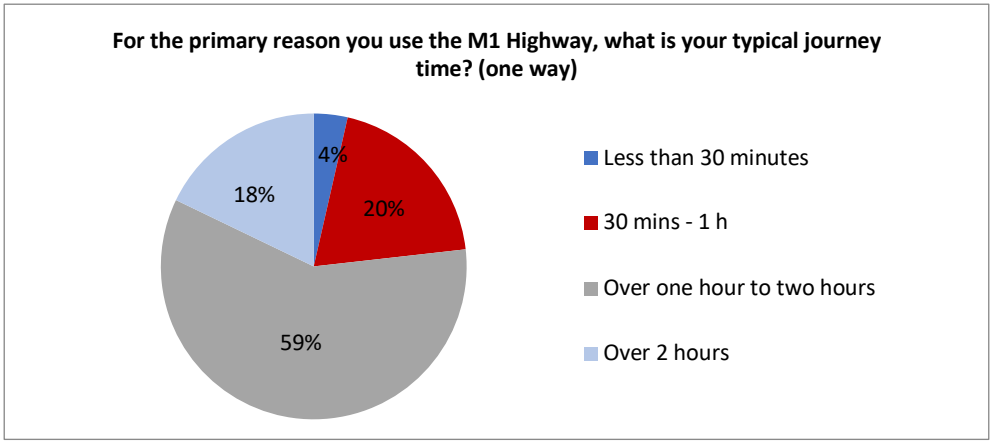


Figure 6 Respondents' typical journey time

Resilience Evaluation

As ITRA uses the idea of a resilience triangle shown schematically in Figure 7 (adapted from Bruneau et al., 2003), here we propose to transpose the results of the questionnaire into what we are calling "tolerance triangles" (Honfi et al., 2018).

Thus, a tolerance triangle is created by the accumulated percentages of respondents willing to tolerate a given service reduction for a given time frame. The next step would then be to compare the tolerance level to the resilience triangle, in order to perform the resilience evaluation and determine where public expectations are not being met (represented by the red area between the curves in Figure 7). Note that in Figure 7 the performance is plotted such that the increased positive value reflects better performance. In the case studied here we will use

"additional travel time" as an indicator of performance. Since these are intuitively plotted as a positive number the triangles that are produced will be turned upside down with positive numbers during the aftermath of the incident and normal performance reflected by a value of 0, thus no additional travel time.

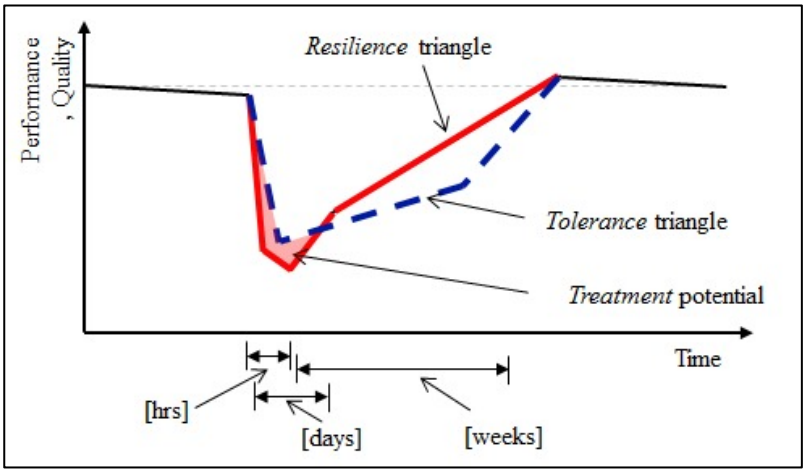


Figure 7 A schematic representation of a "resilience triangle" in red & a "tolerance triangle" in blue. From Honfi et al., 2018.

Közút's performance (the red line in Figure 7) could be evaluated using many different performance criteria. The IMPROVER project has defined the M1 hazards and their probabilities, damage states associated to these and the implications that will have on the local situation for the highway. Thereafter, traffic simulations were performed for different traffic loads and damage states. The performance measures from these simulations are chosen as (1) value of transported goods, based on data by Közút and (2) increased travel time for a specified section of the highway. It is the second of these performance measures that this paper uses to compare with public expectations.

RESULTS

The full results are available in Table 1 in the Annex. The following sections present the results in more detail.

Disaster preparedness, risk awareness and previous disaster experience

Respondents are equally split in terms of disaster preparedness regarding having emergency supplies stocked in their private vehicles (Figure 8). Respondents mostly do not think that serious damage to a bridge will occur in the next year (49%) (Figure 9). However, there is great uncertainty (21%). For the snowstorm scenario, respondents are more unsure (32%), but overall believe it is more unlikely than likely (Figure 10). Respondents are almost equally divided between those who have experienced a disaster and those who have not (49% vs. 50%, with 1% choosing I do not know). For those that have, flood and snowstorm are the most commonly experienced, both of which have recently affected the M1 Highway service in the past.

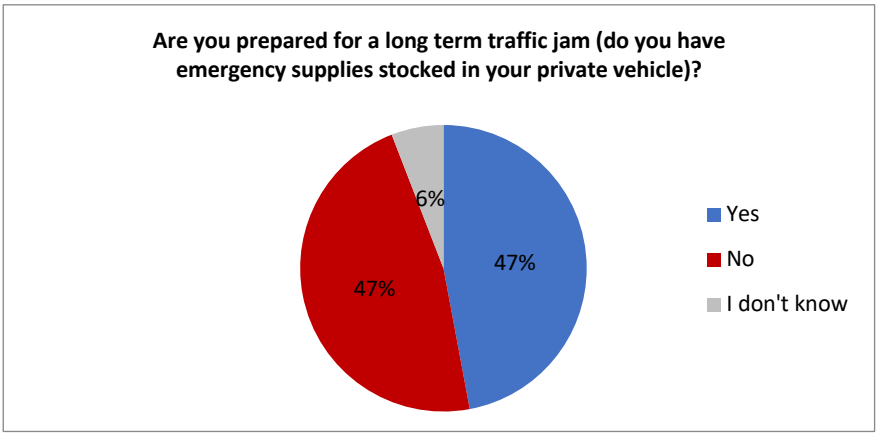


Figure 8 Respondent's declared disaster preparedness

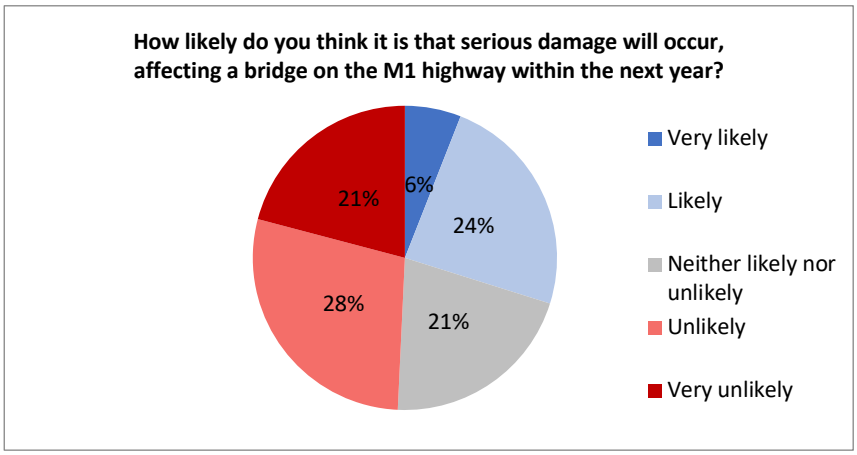


Figure 9 Risk perception: bridge damage

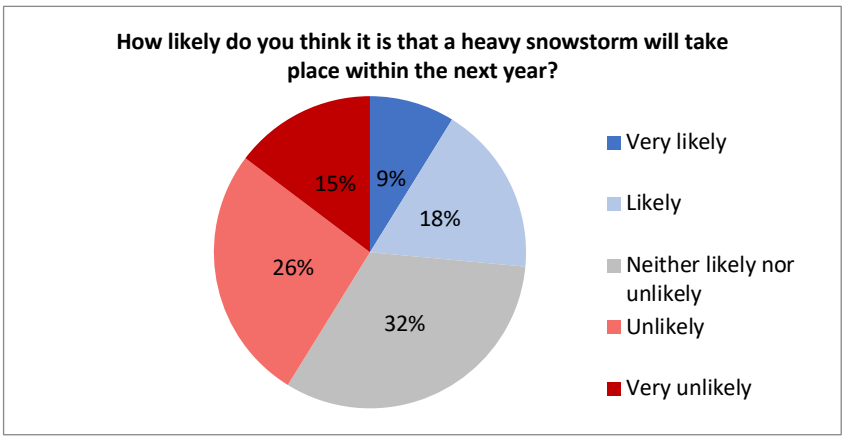


Figure 10 Risk perception: snowstorm

Tolerance triangles

Scenario 1

Additional journey time was asked in regards to four different possible reasons for taking the M1 Highway. Respondents using the highway for work related activities were less likely to tolerate longer delays ($X^2 = 831.39$, $df = 12$, $p < 0.001$). The related additional journey time tolerance triangles are presented in Figure 11. Duration of additional journey time was asked in regards to five different additional journey time scenarios. Unsurprisingly, shorter additional journey times are tolerated by more respondents for longer durations, however the statistical significance of this has yet to be verified ($X^2 = 1806.81$, $df = 28$, $p=0$). The related tolerance triangle is presented in Figure 12.

Scenario 2

Additional journey time was asked in regards to four different possible reasons for taking the M1 Highway. Respondents using the highway for work related activities were less likely to tolerate longer delays ($X^2 = 1341.45$, $df = 12$, $p < 0.001$). The related additional journey time tolerance triangle is presented in Figure 13.

Duration of additional journey time was asked in regards to five different additional journey time scenarios. Unsurprisingly, shorter additional journey times are tolerated by more respondents for longer durations ($X^2 = 1048.81$, $df = 20$, $p < 0.001$). The related delivery tolerance triangle is presented in Figure 14.

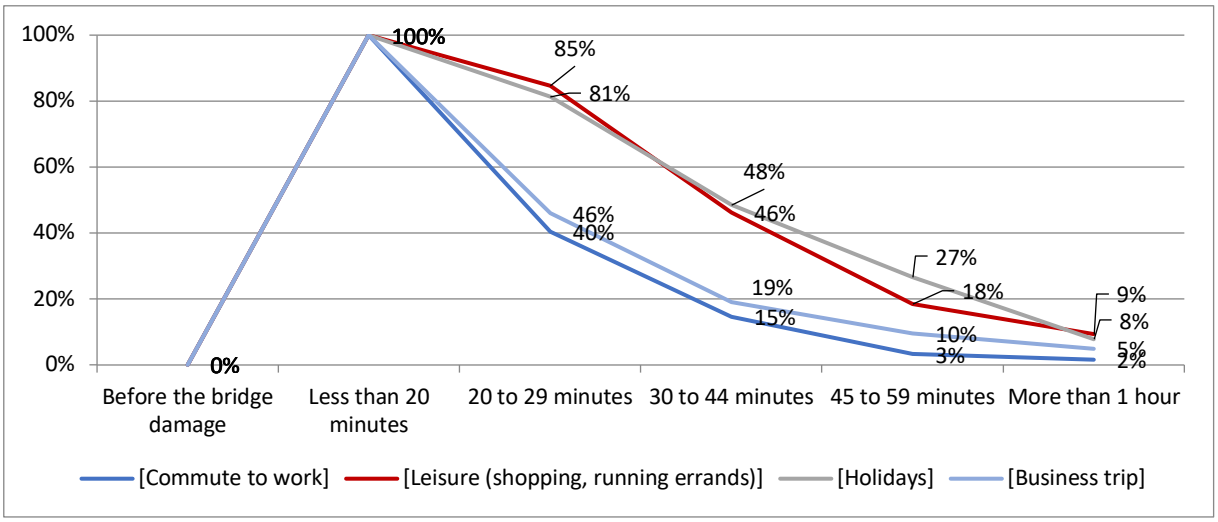


Figure 11 Additional journey time (bridge collision) tolerance triangles

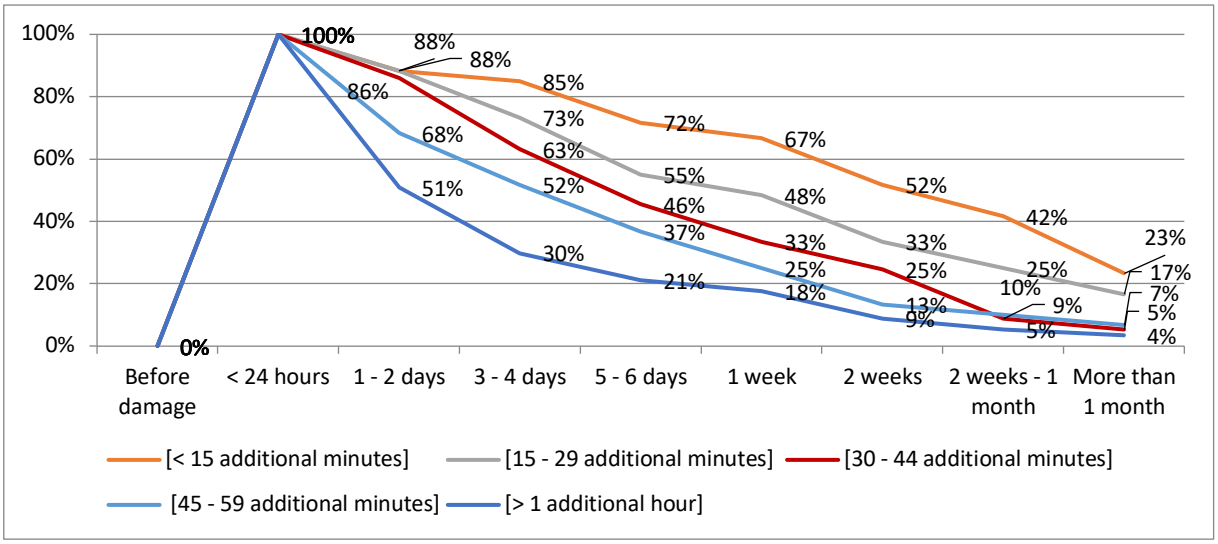


Figure 12 Duration of additional journey time (bridge collision) tolerance triangles

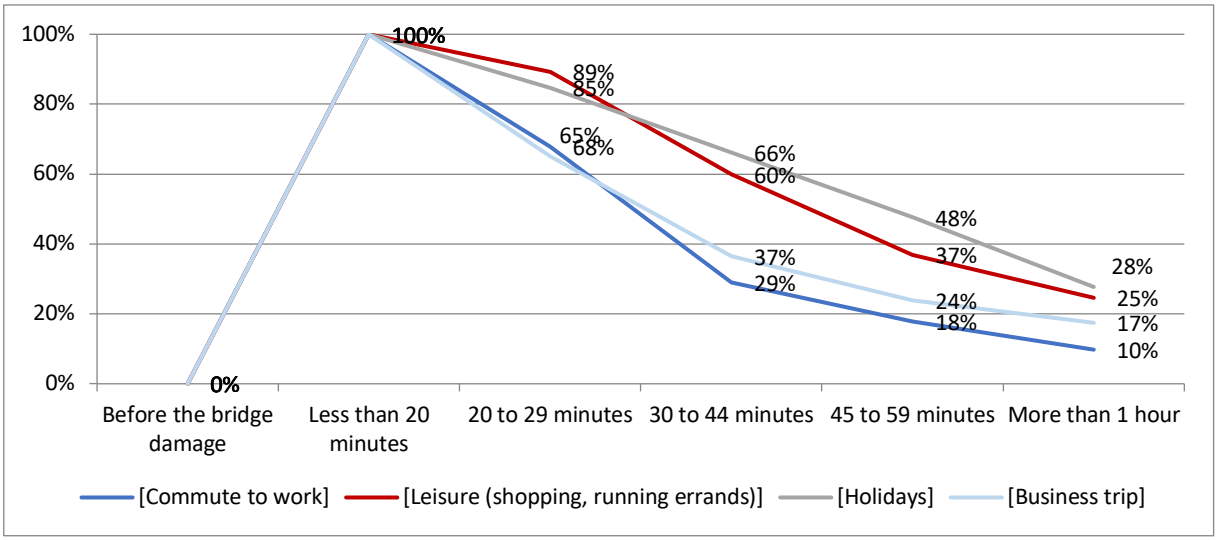


Figure 13 Additional journey time (snowstorm) tolerance triangles

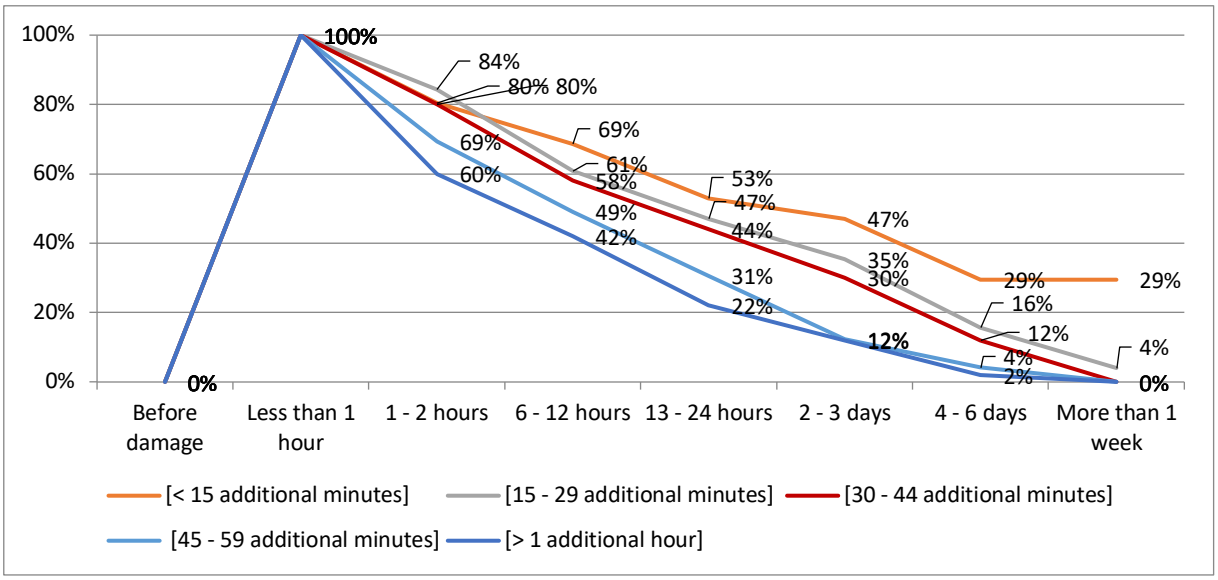


Figure 14 Duration of additional journey time (snowstorm) tolerance triangles

Resilience evaluation

Since most end-users will have unique tolerance to performance loss in infrastructure the tolerance of the public is a distribution which cannot be directly mapped onto a single curve of performance for a given scenario. The information in Figures 11-14 can shine light upon how tolerance varies among the end-users (i.e, does a minor fraction have a very low tolerance compared to the majority or are most end-users in agreement?). However, to be able to set targets one can describe the tolerance as e.g. that of the 75th percentile of the population or, as we will suggest here, as a weighted average of the whole population.

Thus, the tolerance curve for the bridge collision scenario, described as tolerable additional journey time as function of time after the incident, is the average of the different delay times shown in Figure 12 weighted by the percentage of people who stated that delay time as their maximum tolerance. The percentage of respondents that did not accept any of the proposed delay times are assumed to accept nothing but normal performance. This weighted delay time is calculated for each time after the incident.

$$\bar{t}_{Tol}(t_{incident}) = \sum_{I=1}^{X} \frac{n_i(t_{incident})}{N} \times t_{d,i},$$

where $\bar{t}_{Tol}(t_{incident})$ is the weighted average of tolerated time delay after a time $t_{incident}$ since the incident, X is the number of proposed time delays suggested in the questionnaire (the five curves in Figure 12), $n_i(t_{incident})$, is the number of respondents who stated the additional travel time $t_{d,i}$ as their maximum tolerance after time $t_{incident}$ from the incident and N is the total number of respondents. Note that this weighted average is lumped for all four different categories of travel (work commuting, leisure, …). The division between the different categories can easily be made but is not suitable for this low number of respondents.

The comparison of the weighted average tolerance in additional travel time and the estimated performance measure is shown in Figure 15 for the bridge collision. The performance curve is from Honfi et al. (2018) and is representative of a severe damage state due to a collision, a high vehicle rate of 1800 vehicles per hour and present-day resources and strategies. Figure 16 shows the equivalent data for the snowstorm scenario. The performance curve in this case is not estimated using the suggested tools for technological resilience analysis suggested in Honfi et al. (2017) but is an estimation of a realistic scenario based on the March 2013 Budapest snowstorm. Thus, it is important to keep in mind that the performance curves used here do not show the true performance of the system and are used here for illustrative purposes only.

With the tolerance curves derived here it is possible to evaluate the estimated performance for different resources available, different restoration strategies and different damage states. These evaluations will inform the decision makers on the sufficiency of the performance depending on these variables to partially guide the preventive work.

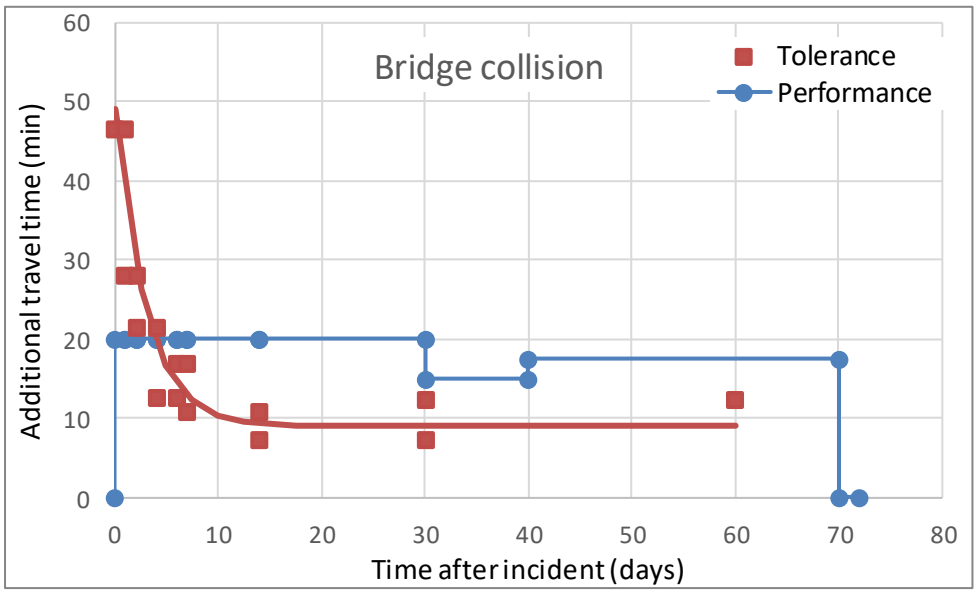


Figure 15 The performance measure of additional travel time (Honfi et al., 2018) evaluated against the tolerance curve for the bridge collision scenario. The red line is an exponential decaying representation of the tolerance data.

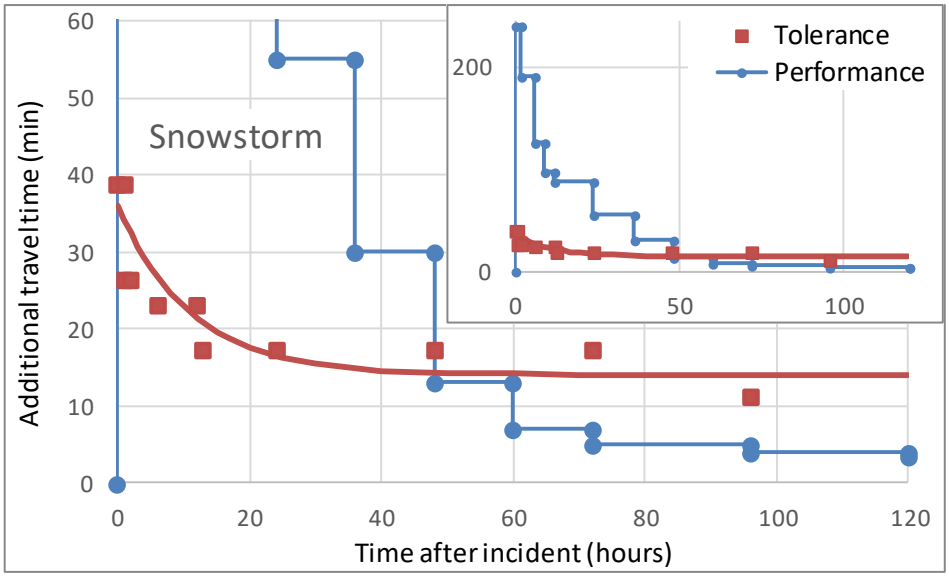


Figure 16 The performance measure of additional travel time evaluated against the tolerance curve for the bridge collision scenario. The inset shows the same data also for the period close to the incident.

DISCUSSION

Public expectations of service level and recovery time

The questionnaire results indicate that respondents are willing to tolerate service disruption in the form of additional journey times in times of crisis. For the four use-cases we presented, in both scenarios, the reason for using the highway highly affects the willingness to tolerate additional journey time. If traveling for work related reasons (commute to work & business trip), respondents were less willing to tolerate longer additional journey times. Thus, it seems that the minimum level of service expected from the public when it comes to work-related travel is between 20 and 44 minutes of additional journey time. When traveling for lesiure or holidays, respondents minimum level of service is an increased level of additional journey time then that of when travelling for work, ranging from 30 to 59 minutes. Unsurprisingly, the longer the additional journey time, the less long the respondents are willing to tolerate the new minimum level of service. For example, in Scenario 1, the majority of respondents are willing to have an additional journey time of 15 minutes for a period of 2 weeks, whereas for an additional journey time of 45 – 59 minutes, respondents choose only 3 - 4 days. The low risk awareness of

respondents indicates that both scenarios would most likely be seen as "unforeseen" events, which could help explain why highway users are so willing to have reduce service levels.

Since most travellers in our study use the M1 Highway for holiday travel, the minimum acceptable level of service recommended is 30 - 44 additional minutes of travel time (chosen by 48% of respondents for scenario 1 and 66% for scenario 2). For this additional journey time, almost half of respondents (46%) consider 5-6 days with additional travel time to fall within a "rapid" recovery for scenario 1, whereas almost half of respondents (44%) consider 13 – 24 hours with additional travel time to fall within a "rapid" recovery for scenario 2. This clearly shows the importance of the crisis scenario on expectations, as the public have demonstrated their understanding that certain disasters require a longer recovery time.

For the two cases used here the tolerance levels are both below and above the performance levels for different time durations after the incident. For scenario 1 (bridge collapse), for the first few days after the incident the expected performance for this scenario is better than the tolerances of the end-users. However, five days after the incident the end-users expect less additional travel time than what is the expected performance from the resilience analysis (for this damage state, these resources and the given strategy). Contrary to the bridge collision scenario, the estimated performance during the early stage of the snowstorm scenario (scenario 2), which is 2 days for this scenario, does not meet end-users' expectations. The very long additional travel times required just after a heavy snowfall is clearly not what the end-users expect. However, the public seem to tolerate small additions to the travel time for a longer period (> 2 days) than what is the estimated performance. While keeping in mind that these results are purely illustrative, they would permit one to advance to the next phase of ICI-REF, *resilience treatment*. For scenario 1, to better meet expectations for long-term recovery, a possible treatment could be the implementation of techniques for quick and efficient damage identification using e.g. structural health monitoring. For scenario 2, it may be beyond the capacity of the operator to meet public expectations. In this case, it is recommended to increase crisis communication during both the prevention and active crisis times. Indeed, information provision has been found to lead to more reasonable expectations of CI operators (Petersen et al., 2018; Buller, 2015).

Success of the method

Despite a low response rate, the questionnaire results demonstrate that it is possible to use this type of method in order to discern the tolerance levels of a given user population of a given CI. Indeed, starting from the same functionality and performance measures as the technical resilience analysis did not inhibit the ability of respondents to state their tolerance levels. Thanks to the use of Living Labs, the questionnaire was able to be developed with inputs from the Hungarian M1 Highway operators and study relevant crisis scenarios and realistic recovery timeframes. The operators at Közút have expressed positive feedback on the methodology and think that the results provide relevant knowledge. Of course, performing the resilience evaluation for all different damage states, recovery strategies and resource availabilities will be the true test of the method and ensure combability between the *resilience analysis* and the *establishment of the context* of the framework. This is part of ongoing work, pending the finalization of the resilience analysis. Thus, the ultimate success of the method is not yet entirely apparent. However, developing the survey in tandem with the resilience analysis parameters did not inhibit data collection and allowed the questionnaire to establish the public's tolerance levels.

As stated in the methodology, in order for the tolerance questionnaire to be comparable to the resilience analysis, the questionnaire also had to be scenario-based. This is because ITRA is dependent on undertaking a risk analysis, which in general are scenario-dependant. Thus, the results are not generalisable to all types of crisis scenarios. However, to analyse resilience of a given CI, it is not necessary to be use a scenario-based method (i.e. to use a different method during the *resilience* analysis phase than ITRA), as certain performance changes will occur regardless of the type of incident that has occurred. In this case, while it should be possible to also use a questionnaire to determine public tolerances, our results demonstrate that the type of crisis does highly affect public expectations. This shows the value of using scenarios when evaluating tolerances, to more fully understand the population. Further, as previous research has shown that nationality plays a big role in public expectations of CI operators in crisis times (Petersen et al., 2018a), it is recommended to perform a questionnaire for each CI individually.

Limitations

Survey

Questionnaires as a research method have certain limitations that maybe overcome with purposeful survey design (Jones & Tanner, 2015). Indeed, when responding to a questionnaire, people often use snap judgement and may

be influenced by emotional or contextual factors (Schwarz & Stack, 1999). For example, perhaps if the survey had been undertaken in winter, traffic delays would be more common and risk awareness for this issue would be higher. When it comes to using a questionnaire to ask about tolerances, question wording may influence responses, as research has demonstrated that when asked if they care about a given issue, people state concern for issues that do not exist (Herrmann et al., 1994). Another issue to consider is whether or not people answer in their own self-interest, claiming to tolerate less so as to not give the CI operators an excuse to perform any lower than absolutely necessary, or in a self-delusionary way, reporting that they are willing to tolerate more than they actually could handle. Another limitation to consider is that as disaster victims rarely passively wait around for someone else to take care of their needs (Quarantelli, 1998), stated tolerances may be for a level of reduced service that is higher than the actual minimum level of service that citizens are capable of tolerating. Another limitation is the sample method used does not allow for representativeness in the sample. The small sample size used here is also a limitation for the generality of the results. Further due to the dissemination method that focused heavily on Hungary, most respondents were Hungarian whereas about 60% of users of the M1 are international users according to Közút. Thus, the tolerance levels for all highway users cannot be said to be known.

Resilience evaluation

It should be mentioned that there are different ways of weighting the answers from the respondent. The method used here is to (1) average the accepted times of additional travel times for each duration after the incident. Another method could be to (2) average the duration after the incident for which the respondent will accept a certain additional travel time. For this specific case there are pros and cons to both methods. Method (1) can give non-monotonic results due to the way the precise question was presented. On the other hand, it represents all the answers better since the relative time of the largest delay time is not orders of magnitude larger than the smallest. Method (2) gives completely monotonic results but since the longest duration of time (>1 month) is so much larger than the smallest duration the final results are heavily reflecting only the answers related to the longest duration period. Both curves give similar results but method (2) cannot extend for much longer that 15 hours (for the case of bridge collapse). This could be improved in constructing a similar questionnaire in the future where the relative magnitude of the different alternatives should be spaced more evenly, or possibly that the respondent is free to write his/her own tolerance of duration without predefined alternatives.

One should also be aware of the fact that the performance measure and tolerances do not precisely reflect the same quantity. The tolerances are based on the respondent tolerance to additional travel time for their characteristic travelling (which differ in length, duration and position between the respondents). Performance is, on the other hand, defined for a fixed section of the M1 highway. Thus, 2nd order effect due to very long ques are therefore not taken into account but that could only be circumvented by performing the traffic flow analysis in a probabilistic manner having prior knowledge about the distribution of length, duration and sections of the highway used by all users… data that presently is not available.

CONCLUSION

This paper set out to establish a methodology using a questionnaire survey to determine public tolerance levels for CI service reduction in crisis times. The questionnaire was designed in such a way as to provide data that would subsequently be usable in the *resilience evaluation* step of IMPROVER ICI-REF. Using a living lab to test the methodology enabled it to ensure relevance to the CI operator. The questionnaire established that the public generally have reasonable expectations towards highway operators during both collision and snowstorm scenarios. However, the expected duration of traffic disturbance after a severe bridge collision is underestimated by the respondents. Additionally, the magnitude of the additional travel time for a short duration after a heavy snowstorm is not reflected in the tolerance of the public.

The minimum level of acceptable service was found to be dependent on the reason for travel, with work-related travel minimums being of a lesser additional journey time. In regards to rapidity of service restoration, as one would have thought, longer additional journey times were tolerated for shorter periods. These declared tolerance levels seem to fall within the response-ability of the CI operator, showcasing once again that the public have reasonable expectations of service levels in crisis times. Based on the main use case of our respondents (holiday travel), it is recommended to have a minimum service level of an additional journey time of 30 – 44 minutes and to rapidly restore normal performance would be restoring it within either 13 – 24 hours for snowstorm or 5 – 6 days for bridge collision. This pilot test then has successfully demonstrated the ability to use questionnaires as a means to discover public tolerances within the *establish the context* step of ICI-REF.

While the questionnaire results as first shown can provide a more general target, to successfully carry out a *resilience evaluation*, the results were then used to calculated the weighted average tolerance of the whole population. As such, the comparison of the tolerance criteria from *establishing the context* to the *resilience*

analysis was demonstrated. As the *resilience analysis* is still ongoing work within the IMPROVER project, the performance curves used here do not show the true performance of the system. Nevertheless, they were useful as an illustration of the resilience evaluation methodology, demonstrating the compatibility of a tolerance questionnaire with resilience analysis.

Future work includes comparing the results of this questionnaire to the plethora of results from the *resilience analysis*, thus performing the *resilience evaluation* step of the framework for different decision parameters. Followed by the development of a *resilience treatment* plan for the Hungarian M1 Highway. Future work will also build on this methodology to perform a similar questionnaire-based study of tolerances in other IMPROVER Living Labs. Lastly, the IMPROVER project will develop a guide for practitioners on how to design and implement tolerance questionnaires.

ACKNOWLEDGMENTS

The IMPROVER project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653390.

REFERENCES

Barker, B. (2013). New Focus for Weathering Storms: Customer Resilience. *In EPRI Journal*.

Bruneau, M., Chang, S.. Eguchi, R., Lee, G., O'Rourke, T., Reinhorn, A., Shinozuka, M., Tierney, K., Wallace, W., & von Winterfeldt, D. (2003). A Framework to Quantita-tively Assess and Enhance the Seismic Resilience of Communities. *Earthquake Spectra: November 2003, Vol. 19, No. 4, pp. 733-752*. DOI: 10.1193/1.1623497

Buller, A. (2015, July 10). Closing the Gap: Expectations versus Capabilities. *PA Times*. Retrieved from: http://patimes.org/closing-gap-expectations-capabilities/

Centre for Transport & Society. (2015). Independent Analytical Review for a Road User Satisfaction Survey. https://www.transportfocus.org.uk/research-publications/publications/independent-analytical-review-for-a-road-user-satisfaction-survey/

Dahlberg, R. Do you have a Plan B? Integrating adaptive capacities into infrastructure preparedness planning. *Journal of Contingencies and Crisis Management.* DOI: 10.1111/1468-5973.12203

Honfi, D., Lange, D., Malm, A., Mindykowski, P., Alheib, M., Bouffier, C., Cauvin, L., Willot, A., Ioannou, I., & Rød, B. (2017). Technological resilience concepts applied to critical infrastructure. *IMPROVER projet deliverable D3.2.*

Honfi, D., Lundin, E., Sjöström, J., Lange, D., Vigh, L. G., Petersen, L., Ioannou, I. (2018). Report of technological resilience concepts applied to living labs. *IMPROVER project deliverable D3.3*.

Jones, L. & Tanner, T. (2015). Measuring 'subjective resilience' using people's perceptions to quantify household resilience. Overseas Development Institute.

Lange, D., Honfi, D., Theocharidou, M., Giannopoulos, G., Reitan, N. K., Storesund, K. (2017). Incorporation of resilience assess-ment in Critical Infrastructure risk assessment frameworks, *In: Safety and Reliability – Theory and Applications,* ISBN 978-1-138-62937-0, p. 1031-1038.

Nakanishi, H., Black, J. and Matsuo, K. (2014). Disaster resilience in transportation: Japan earthquake and tsunami 2011. *International Journal of Disaster Resilience in the Built Environment. Vol 5 No. 4, Pp. 341-361.* doi: 10.1108/IJDRBE-12-2012-0039

Nguyen, K. V., & James, H. J. (2013). Measuring household resilience to floods: A case study in the Vietnamese Me-kong river del-ta. Ecology and Society 18(3): 13. 2013.

OECD. (2001). Performance Indicators for the Road Sector: Summary of the field tests. ITRD N°E 108267.

Peteresen, L, Fallou, L, Carreira, E., & Utkin, A. (2017a). Public tolerance levels of transportation resilience: a focus on the Oresund region within the IMPROVER Project. *Critical Information Infrastructures Security*, *12th International Conference, CRITIS 2017, Lucca, Italy, October 8-13, 2017, Revised Selected Papers*.

Petersen, L., Fallou, L., Reilly, P., & Serafinelli, E. (2017b). Exploring public expectations for aid from critical infrastructure operators. *Proceedings of the 52nd ESReDA Seminar Hosted by the Lithuanian Energy Institute & Vytautas Magnus University May 30-31, 2017, Kaunas, Lithuania, p. 68 – 81. EUR 28803, EN, Publications Office of the European Union, Luxembourg, 2017*, ISBN 978-92-79-73870-8. doi:10.2760/07157

Petersen, L., Fallou, L., Reilly, P., Serafinelli, E. (2018a). Public expectations of critical infrastructure operators

in times of crisis. *Sustainable and Resilient Infrastructure*. doi: 10.1080/23789689.2018.1469358

Petersen, L., E. Lundin, J. Sjöström, D. Lange & R. Teixeira. (2018b). Creating comparable public tolerance and technical performance measures for critical infrastructure resilience evaluation. *Safety and Reliability – Safe Societies in a Changing World. Proceedings of ESREL 2018, June 17-21, 2018, Trondheim, Norway.* doi: 10.1201/9781351174664

Quarantelli E.L. (1998). Major criteria for judging disaster planning and managing and their applicability in developing societies. International Seminar on the Quality of Life and Environmental Risks held in Rio di Janeiro, Brazil.

Regional Australia Institute. (2013). From Recovery to Renewal: Case Study Reports. April, 2013. http://www.regionalaustralia.org.au/wp-content/uploads/2013/06/RAI-Natural-Disasters-Report-Case-Studies.pdf, last ac-cessed 21/04/2016

Schwarz, N., & Strack, F. (1999). Reports of subjective well-being: Judgemental processes and their methodological implications. in: Jones, L. and Tanner, T. (2015) Measuring 'subjective resilience' using people's perceptions to quantify house-hold resilience. Working paper 423. *Overseas Development Institute, London.*

Transport focus. (2017). National Road Users' Satisfaction Survey 2016-2017. https://www.transportfocus.org.uk/research-publications/publications/national-road-users-satisfaction-survey-2016-2017/

ANNEX

Table 1 Questionnaire results in number of respondents per answer.

Are you prepared for a long-term traffic jam (do you have emergency supplies stocked in your private vehicle)?				
Yes	32			
No	32			
I don't know	4			
How likely do you think it is that a heavy snowstorm will take place within the next year?				
Very likely	6			
Likely	12			
Neither likely nor unlikely	22			
Unlikely	18			
Very unlikely	10			
How likely do you think it is that serious damage will occur, affecting a bridge on the M1 highway within the next year?				
Very likely	4			
Likely	16			
Neither likely nor unlikely	14			
Unlikely	19			
Very unlikely	14			
Have you ever witnessed any disasters? A disaster would be an event that significantly affects the quality, quantity or availability of the transportation infrastructure				
Yes	33			
No	34			
I don't know	1			
After the serious damage to the bridge leading to the use of deviations, how much additional journey time are you willing to tolerate when using a personal vehicle or bus on the deviation route when travelling for…?				
	Commute to work	Leisure	Holidays	Business trip
Less than 20 minutes	37	10	12	34
20 to 29 minutes	16	25	21	17
30 to 44 minutes	7	18	14	6
45 to 59 minutes	1	6	12	3
More than 1 hour	1	6	5	3

After the serious damage to the bridge leading to the use of deviations, for your PRIMARY use of the highway, how long would you be willing to put up with an additional journey time of…?					
	< 15 additional minutes	15 - 29 additional minutes	30 - 44 additional minutes	45 – 59 additional minutes	> 1 additional hour
< 24 hours	7	7	8	19	28
1 - 2 days	2	9	13	10	12
3 - 4 days	8	11	10	9	5
5 - 6 days	3	4	7	7	2
1 week	9	9	5	7	5
2 weeks	6	5	9	2	2
2 weeks - 1 month	11	5	2	2	1
More than 1 month	14	10	3	4	2

After the M1 highway is no longer open due to snow, how much additional journey time are you willing to tolerate when using a personal vehicle on the deviation route when travelling for…?				
	Commute to work	Leisure	Holidays	Business trip
Less than 20 minutes	20	7	10	22
20 to 29 minutes	24	19	12	18
30 to 44 minutes	7	15	12	8
45 to 59 minutes	5	8	13	4
More than 1 hour	6	16	18	11

After the M1 highway is no longer open due to snow, for your PRIMARY use of the highway, how long would you be willing to put up with an additional journey time of…?					
	< 15 additional minutes	15 - 29 additional minutes	30 - 44 additional minutes	45 – 59 additional minutes	> 1 additional hour
Less than 1 hour	10	8	10	15	20
1 - 2 hours	6	12	11	10	9
6 - 12 hours	8	7	7	9	10
13 - 24 hours	3	6	7	9	5
2 - 3 days	9	10	9	4	5
4 - 6 days	0	6	6	2	1
More than 1 week	15	2	0	0	0

Enhanced Crisis-Preparation of Critical Infrastructures through a Participatory Qualitative-Quantitative Interdependency Analysis Approach

Axel Dierich
inter 3 Institute for Resource Management
dierich@inter3.de

Katerina Tzavella
Technische Hochschule Köln
katerina.tzavella@th-koeln.de

Neysa Jacqueline Setiadi
Technische Hochschule Köln
neysajacqueline@yahoo.com

Alexander Fekete
Technische Hochschule Köln
alexander.fekete@th-koeln.de

Florian Neisser
Technische Hochschule Köln
florian.neisser@th-koeln.de

ABSTRACT

Critical Infrastructure (CI) failures are aggravated by cascading effects due to interdependencies between different infrastructure systems and with emergency management. Findings of the German, BMBF-funded research project "CIRMin" highlight needs for concrete assessments of such interdependencies. Driven by challenges of limited data and knowledge accessibility, the developed approach integrates qualitative information from expert interviews and discussions with quantitative, place-based analyses in three selected German cities and an adjacent county.

This paper particularly discusses how the mixed methods approach has been operationalized. Based on anonymized findings, it provides a comprehensive guidance to interdependency analysis, from survey and categorization of system elements and interrelations, their possible mutual impacts, to zooming into selected dependencies through GIS mapping. This facilitates reliably assessing the need for maintenance of critical functionalities in crisis situations, available resources, auxiliary powers, and optimization of response time.

Keywords:

Critical Infrastructure Protection, Interdependency, Resilience, Vulnerability, Cascading Effects, Emergency Management, Participatory Approach

INTRODUCTION

To build up resilience of Critical Infrastructures (CI), infrastructure operators, public crisis managers and emergency responders need to get a joint understanding of the entire system of systems. With automation, digitalization and efficiency gains, CI systems become increasingly complex, and so do their interdependencies. Preemptive risk management, as well as ad-hoc crisis response therefore need to consider this interconnectedness (Rinaldi et al., 2001; Little, 2002; O´Rourke, 2007; Lenz, 2009; Utne et al., 2011; Ouyang, 2014). As Georgios Giannopoulos of the Joint Research Centre of the European Commission puts it, „a resilience analysis requires assessing the infrastructure from a holistic point of view, enhancing coordination

and timely response throughout the interdependencies" (Giannopoulos et al., 2012, p. 38). Hence, risks can „be tackled by increasing the capacity of the dependent nodes to withstand the perturbation" (ibid.).

However, there is a general tendency among infrastructure operators to focus merely on their own systems – resulting in little exchange of information to identify the overall connectedness (Bach et al., 2013). As Grafenauer et al. (2018) have put it: "As systems become more complex, a clear overview on the consequences of a problem is harder to obtain". An insufficient understanding of the dynamics of interdependencies and of the dynamics of their interplay however may result in ineffective response and poor coordination between decision makers and disaster managers before, during and after a disaster (Baloye & Palamuleni, 2016; Faturechi & Miller-Hooks, 2015), which can lead to serious delays in emergency service delivery.

These aspects were the key motivation for performing a qualitative interdependency and impact analysis in the "Critical Infrastructures Resilience as a Minimum Supply Concept" (CIRMin) research project, running from June 2016 to May 2019. It aims at strengthening the (joint) preparedness and coping capacity of Critical Infrastructures in Germany, in order to optimize minimal supply for the population in case of CI break-downs. A reliable information basis for decision-making (Clarke, 1999; Heinecke, 2006; Weimer-Jehle 2015) was created through a thorough system analysis, involving all relevant actors and thus taking inter- and trans-sectoral dynamics of the systems' functioning into consideration (López-Silva et al., 2015; Schätter et al., 2014; Reissberg, 2012; Giannopoulos et al., 2012). It was accompanied by an open-data-based GIS spatial analysis and visualization which supported the analytical documentations of key sensitivities, weak spots and demands.

The CIRMin approach was mainly build on a personal exchange of information among experts and with the researchers. Emergency response, electricity and water supply have been selected as focal sectors, according to their relevance for civil security in Germany. Through bringing experts from those and further CI sectors together prior to hazard events, it was intended to provide them with a clearer and focused understanding of interlinkages and dependencies between their different infrastructure sectors and thus to jointly enhance resilience building.

As case studies, three municipalities (in Western Germany, Land of North Rhine-Westphalia) have been selected since this administrative level bears first responsibility for crisis management in Germany. In order to enable studies on differences and similarities, a metropole city, its neighboring, mixed rural/peri-urban district and another major city were selected.

RESEARCH GAP

The literature review related to CI interdependencies and methodological approaches included scientific publications, grey literature such as guidelines or technical reports and reports on previous or ongoing German and EU research projects. The following subchapters provide an overview of different approaches to interdependency analysis as well as a conceptual basis for the performed GIS analysis.

Methodological Approaches to Assessing CI interdependency

Most approaches of interdependency analysis attempt some kind of quantitative modelling (See e.g. Kröger, 2012; Pederson et al., 2006; Bloomfield et al., 2009; Ouyang, 2014; Dudenhoeffer & Permann, 2006; Hokstad et al., 2012). However, as Ouyang (2014) puts it in an overview, most approaches need medium to large quantities of input data with often difficult data accessibility. Also reviews from Bloomfield et al. (2009) and Pederson et al. (2006) discuss the challenges of data requirements, finding data sets and providing realistic demonstrations. It is often difficult to capture the potential sectoral and intersectoral cascading effects of supply breakdowns of critical sectors such as electricity and water in their complexity. On the other side, most purely quantitative data analyses have been limited to modeling systems in a near-realistic sense that did not sufficiently reflect the complex and often tight coupling, factors of human behavior and thus, hidden logics of CI systems (see e.g. Perrow, 1984). Also, security concerns of misuse by attackers and data sensitivity concerns are major constraints to information sharing. Bloomfield et al. (2009) therefore propose qualitative approaches that involve different stakeholder groups at least as a preliminary step.

Another challenge in research projects so far seemed to be consequently applying an intersectoral approach: Various research projects like MICIE[i], AFTER[ii], TankNotStrom[iii], MIA[iv], STREST[v], Smart Resilience[vi], NoWa II[vii], KontiKat[viii] and studies such as the TAB Report (Petermann et al., 2010) successfully tackled the above-described challenges of information exchange. But these projects so far only analyzed unidirectional

dependencies from single CI sectors, yet no holistic interdependency assessments. The projects Casceff[ix], Predict[x], DRIVER[xi], and Crisma[xii] developed practical tools with a high involvement of practitioners, to assess possible impacts of incidents to (inter)dependent systems at a higher abstraction level, i.e. systems of infrastructure sectors and their services. They thus demonstrated the importance of actively involving the practitioners from various sectors in development of interdependent infrastructure models. But still, this research mainly relied on or was limited to one or two CI systems (Barthe-Delanoë et al., 2015). Broadening the scope of application of these data bases to the entire system of systems of Critical Infrastructures and crisis management would make them hardly manageable. This "requires extensive knowledge" about a metropolitan area, "including e.g. building inventory, systems, and suitable data to characterize the employed hazard models" (Garcia-Aristizabal et al., 2015, p. 9).

Projects at the European level with an intersectoral approach (such as the Snowball[xiii] project and Fortress[xiv]) have developed computer simulations of various supply sectors. They provided a very far-reaching approach to viewing infrastructures in their vast complexity as socio-technological systems. Their developed models are user-centric by involving actively the practitioners and match demands on modern CI resilience approaches (Bach et al., 2013). But in turn, these elaborate processes rely on vast data sets about a handful of very specific impact scenarios. As an approach to identifying the key needs for action to prepare a city or region for different kinds of CI outages, they seem to be too costly and not easy to handle.

Use of GIS Analysis

The development of spatial technologies has been driven by needs for better, easier (Mansor et al., 2004) and quicker decision-making for emergency response, and for the overall resilience building (GAR, 2015). Many of the critical problems that arise with extreme events such as floods or earthquakes are inherently spatial, e.g. the extent of the disaster, on-site crises and number of people in need (Tzavella et al., 2017).

GIS are useful for emergency management by visually displaying key information before and most importantly during an emergency event (Fekete et al., 2016; Tzavella et al., 2017). In CIRMin, information about disaster impacts on a system were integrated with emergency operations capability (Petit et. al., 2015), to better understand and anticipate the consequences of an incident and to support incident management activities (cf. Petit et al., 2014). Specifically, GIS have been recognized as useful tools to determine the changes in impact on a geographic area (Robert et. al., 2015).

Scientific advances in utilizing spatial information are demanded in the areas of CI asset mapping, adding additional context information, such as technical susceptibility of system components or social vulnerability of the supplied population (Fekete, 2012a). However, such exposure assessments are not sufficient to capture effects outside of the initial damage area (such as the flood-zone), which is typical for interdependent and network type of CI services such as electricity grids (Fekete, et al. 2017). Spatially explicit interdependency assessments between CIs reaching beyond e.g. unidirectional dependencies from resources or impacts, are still lacking for Germany.

CONCEPTUAL BASIS OF THE APPROACH

Definition of CI

Critical Infrastructures are defined differently, while overlapping in stressing vital or essential infrastructure elements and processes from the viewpoint of a (mostly national) government perspective (US Government, 1996; European Commission, 2008, FMIG, 2009). In Germany, CI are defined by importance to the state if their failure can cause major damages or destabilization of public order (FMIG, 2009). For this study, this definition of Critical Infrastructures is used: "*organizational and physical structures and facilities of such vital importance to a nation's society and economy that their failure or degradation would result in sustained supply shortages, significant disruption of public safety and security, or other dramatic consequences" (*FMIG, 2009, p.3).
The CI in Germany include nine sectors and selected branches (FMIG, 2009), wherein water supply, electricity supply, and emergency response, which are the focus of the study, are listed.

Types of Interdependency

Rinaldi et al. (2001) define connections between infrastructures as unidirectional (dependency) or bidirectional (interdependency). Within the view of complex systems, many infrastructures are connected one way or

another, directly and indirectly with each other, so that it is necessary to assess the interdependency in a holistic and systemic way. Interdependent infrastructures also display a wide range of spatial, temporal, operational, and organizational characteristics, which can affect their ability to adapt to changing system conditions (Rinaldi et al., 2001).

In this paper, the dimensions of interdependency used are based on the interdependency concepts from Rinaldi et al. (2001; also: Turoff et al., 2014):

i) Physical interdependency: the state of each is dependent on the material outputs of the other
ii) Informational interdependency[1]: the state of an infrastructure depends on information transmitted through the information infrastructure
iii) Geographic interdependency**:** a local environmental event can create state changes in several infrastructures
iv) Logical interdependency: social and political processes

Conceptual Principals

The resilience of complex systems of CI can be observed using a systemic and biocybernetic lens, regarding infrastructures as dynamic and to a large degree self-steering systems. Here, Vester (1988; 1991; 2012) describes biocybernetic systems as examples for self-contained – and in a sense resilient – systems and sub-systems, which use a set of rules that make them function in an optimal way. Projecting these examples from nature on water, electricity or gas supply, transportation, ICT, emergency response and so on, helps in understanding the dynamics, the existing connections and possible interactions within and between the systems and thus the overall complexity of critical infrastructures.

For the interdependency analysis, the Vester (1991; 2012; see also Wilms, 2006) approach of system and sensitivity analysis for complex systems, as adapted by Dierich et al. (2012) (see also inter 3, 2013) to the specific context of interdependent critical infrastructure systems, has been applied. The method was advanced by integrating the concepts by Rinaldi et al. (2001) for systematic classification of interdependencies and Bagheri & Ghorbani (2008) for capturing the variability and dynamic behavior of the complex systems based on a five dimensions model framework.

METHODOLOGICAL APPROACH

The methodological activities in CIRMin took the above described state of the art into consideration to develop the mixed qualitative-quantitative approach of analyzing and mapping the interdependencies between various infrastructure sectors at manageable effort and for crisis situations in general. Employing "Fuzzy Logic" (Vester, 2012; Malik Management Zentrum, 2014) by means of reducing the information depth of the analysis of systems and their elements, the method described in the following was deemed appropriate to solve the above-mentioned handicap of purely data-based decision-support systems.

Sources for data

The basis for the study was the engagement of representatives from CI operators and other project partners from city, regional and national administration. For each case study, representatives from relevant operating companies (electricity supply grid operators, transmission grid operators, water suppliers, wastewater and flooding management and ICT operators) were involved, as well as municipal disaster management officials and emergency responders.

[1] There is a slight adjustment to the concept of Rinaldi et al. in this study, as 'informational interdependency' was used instead of 'cyber interdependency'. Rinaldi et al actually defined it in a wider sense as the dependency on information flow or exchange taking into consideration the actors involved, and as the information and communication technology used. For the study, we deemed communication and exchange of information among actors an important focus, and therefore use the widened term of 'informational interdependency' as defined above.

Qualitative and quantitative analyses have been conducted in parallel with each other. For gathering the qualitative information, semi-structured interviews and moderated focus group discussions in expert workshops served as primary data source. In total, 18 detailed (2-3 hours) interviews with in each case 1-3 participating stakeholders, as well as further telephone interviews have been conducted. Uncertainties have been minimized by comparison of expert views and their dialogic validation. Six expert workshops involving each 10-15 stakeholders and about 10 researchers took place at decisive points of each methodological step and served to discuss findings, jointly draw conclusions from them and perform key analytical steps such as the Cross-Impact-Analysis. Their structure varied from focused discussion to intense co-working. Participants slightly varied but at least the focal CI units and agencies as mentioned above were always represented - with one exception when operators from another region in Germany were brought together to evaluate the transferability of the findings of the interdependency analysis.

Quantitative analysis using GIS applications has been based mainly on available open-source (OS data) and authoritative ('official') data, and its results have been verified by the experts in an iterative process. The advantage of using OS data or even data that is produced voluntarily on-site by the people in need is that it is the most up-to-date data that the emergency responders can have at hand before and specifically during a crisis (however, always depending on the type of crisis) (Tzavella et al., 2017). For this study, before providing findings to local authorities and to the public, they needed to be screened and selected according to security and data sensitivity demands. This integrative and joint process provides new empirical and expert-verified information and at the same time further strengthens collaboration and information exchange among CI and emergency management actors.

Qualitative Interdependency Analysis Steps

Following the concepts discussed previously, the chosen approach to system analysis incorporated the identification and description of critical infrastructure elements and (inter)dependencies in a holistic picture. Different types of systemic elements have been distinguished for the analysis of the systems, together with relational processes and interdependencies. As a further step, through the sensitivity analysis according to Vester (1991; 2012), the identified system elements were aggregated - again with intensive participation of the CI stakeholders - to impact factors and juxtaposed in a cross-impact-matrix to assess their reactivity and dynamic character. The relevant stakeholders were brought together in a workshop, in order to agree on the definition of a limited number of impact factors and discuss and value their interdependencies.

Through reducing their overall complexity, a complete overview of the interwoven CI systems was to be achieved; however, zooming into them and finding accurate and reliable information about particular elements and relationships should remain possible. In both system analysis and discussion of the sensitivity of the systems, the linkages were considered more important than the singular assets, technologies, actions, etc. Therefore, structures and processes were considered in an integrated way.

Quantitative Analysis

The main idea of linking quantitative GIS analysis to the qualitative interdependency analysis was to use the capabilities of GIS in terms of i) visualizing and pinpointing focal interdependencies in a detailed manner and ii) further analyzing, verifying and complementing the gained information. In the opposite sense, the GIS analysis also examined the qualitative results for needs of further detailed analysis.

Data was processed through the Extract-Transform-Load (ETL) method[xv], also to allow for data interoperability. In order to simplify and semi-automate the processes, spatial ETL tools were used[2], for e.g.:

- Filtering attributes and merging them with other feature classes
- Using attribute values to create unique feature classes on the fly

[2] Spatial ETL tools are user-created geoprocessing tools that can transform data between different data models and different file formats. These tools are capable of a wide range of processes and data flows, from simple format translations to complex transformations, which restructure geometry and attributes. They can be used as stand-alone geoprocessing tools or run as part of a Python script tool (see https://pro.arcgis.com/en/pro-app/help/data/data-interoperability/spatial-etl-tools.htm).

- Separating data using test criteria
- Creating line features from coordinate values.

Collected data from different sources has been integrated in an ArcGIS environment. Specifically, available OS geodata have been utilized stemming from projects such as OpenStreetMap, provided and maintained by the community of Geofabrik[xvi], the city of Cologne[xvii] and the international commission of the Rhine[xviii] on actual damages, flood extent, etc. The flood extent for the area of Cologne was downloaded from the Rhine Atlas (IKSR, 2001; Rhine Atlas 2015).

After the initial spatial assessments and GIS visualisations, results and some conclusions were presented to the experts so to verify them. The quantitative research has deliberately been designed as an iterative process of building a joint knowledge basis for CI protection and emergency management. Such participatory GIS approaches have already been applied in other thematic areas (e.g. Pfeffer et al., 2011; Brennan-Horley & Gibson, 2009; Kwan & Knigge, 2006)

DATA ANALYSIS AND EXEMPLARY RESULTS

The following section shows how the interdependency analysis can be performed in four analytical steps and presents some anonymized and generalized results that are based on the actual results from the case studies[3]. For the quantitative (GIS) analysis, maps containing non-sensitive information and using open source data are presented for the city of Cologne.

The following analytical steps have been conducted:

1. identifying and categorizing key CI processes and elements;
2. analyzing interdependencies between elements within and across sectors;
3. cross-impact-analysis: clustering of elements to impact factors and valuing impacts;
4. combining the qualitative analysis results with quantitative (GIS) analysis.

Key CI Processes and Elements

Interviews and discussions with the infrastructure operators and emergency responders in the case study areas provided a thorough understanding of i) processes and elements which are important to deliver the respective services to the community, and ii) interdependency linkages with other infrastructures. Given information was questioned during the interviews with regard to possible supply outage scenarios. The following Table 1 provides a few generalized processes and associated elements - out of the hundreds identified - that applied to all four case studies.

[3] The actual results cannot be made public in detail, in order to respect confidentiality and sensitivity of the data. Selected findings have been slightly altered and thus anonymized, to be able to exemplarily show them in this paper.

Table 1: Selected examples of described processes and elements (Source: own table)

Example	Infrastructure	Process	Element(s)	Qualitative description
1	electricity supply	supply distribution	supply network and supply sub-station	network structure, supply areas, existing redundancies
2	water supply	network regulation and repair management	control center, which is linked with alert service	main point for information flow and contact with other responsible divisions as well as repair works during supply breakdowns, communication media
3	water supply	repair management	on-call duty and repairing vehicles	cooperation with external sources, capacity and repairing time
4	water supply	repair management	switching the distribution network system	network structure (redundancies), automatic or manual, estimated switching time
5	emergency response	emergency operation	operation leader	procedure in operation and decision making, cooperation with other actors

To analyze and evaluate the systems and processes graphically, elements were categorized as follows:

- actors (depicted as squares)
- technological processes and facilities (depicted as circles)
- resources (depicted as hexagons)
- measures (depicted as arrow-like hexagons)
- environmental conditions (depicted as rhombuses) and
- entire infrastructure systems (depicted as octagons).

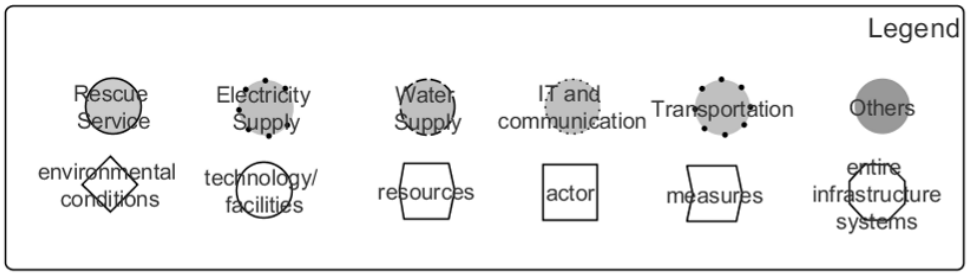


Figure 1: Categorization of elements

Interdependencies Between Elements Within and Across Sectors

As previously mentioned, the interdependencies between elements were categorized as physical, informational geographical, and logical interdependencies. Technical and informational interdependencies clearly prevailed over geographical and logical ones. Exemplary interdependencies are listed in Table 2:

Table 2: Selected interdependencies based on interdependency dimensions adapted from Rinaldi et al. (2001) (Source: own table)

Sub-process	Interdependencies			
	physical	**informational**	**geographical**	**logical**
Notification of disruption and mobilizing resources	Electricity supply of control center, electricity supply of IT system and communication media	Mobilizing resources for (manual) repairing activities Contact with fire brigade	In case of unavailable (public) ICT: distance to person/location (for e.g. courier)	Legal priority of public communication service in case of disruption
Repairing activities	Electricity supply, transportation network, fuel supply, supply with spare parts, external service firms (e.g. civil engineering)	Information exchange between control center, repairing personnel, other actors (fire brigade and police forces, crisis unit)	Accessing the affected areas, proximity to other mains, assets and supply pipes/lines	Existing contract with external service firms, prioritization
Dispatching of emergency responders and vehicles/ engines	Electricity, water, heat and food supply of fire brigade control center Fuel supply of vehicles	In case of electricity cuts: Information about their severity, information about CI (location, capacity of existing emergency power generators)	Distances, traffic, road conditions, degree and spatial extension of population/ CIs affected	Prioritization of emergency operations

As an overview, all interdependencies found in a case study have also been depicted graphically, as shown exemplarily in Figure 2.

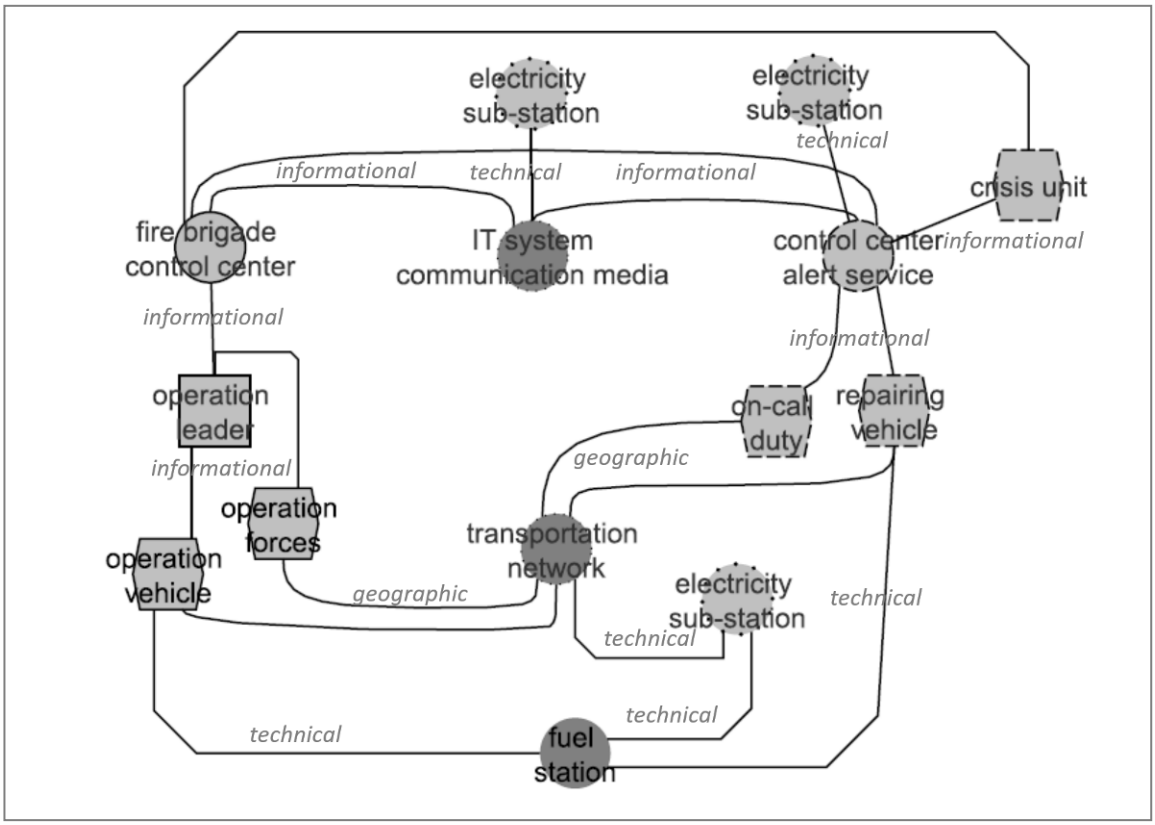


Figure 2: Visualization of the exemplary processes, elements and their interdependencies (Source: own figure)

In the simplified sub-system (Figure 2), information about any disruptions in day-to-day operation through the remote monitoring system or through notification by the customers is collected at the control center, which will in turn notify the repairing service or, in major events, the crisis management unit. The repairing service mobilizes its resources (vehicles with on-call duty) using available communication devices, and the repairing time would depend on the capacity and location of these resources, as well as on the traffic and street/road conditions (transportation network) on the way to the affected location. The service vehicles also rely on supply of fuel at petrol stations, which in turn rely on electricity. In case of a more severe supply disruption, contacts will be established, and information will be exchanged between the control center of the water supply operator and the control center of the emergency responder (fire brigade) for preparing possible operations. On the other hand, the functionalities of the control center depend on electricity supply from electricity substations (although with redundancies in the supply network and own emergency power generation capacities).

This example only shows a small part of the analysis. The whole system analysis at the end would look more complex, as exemplarily shown in Figure 3.

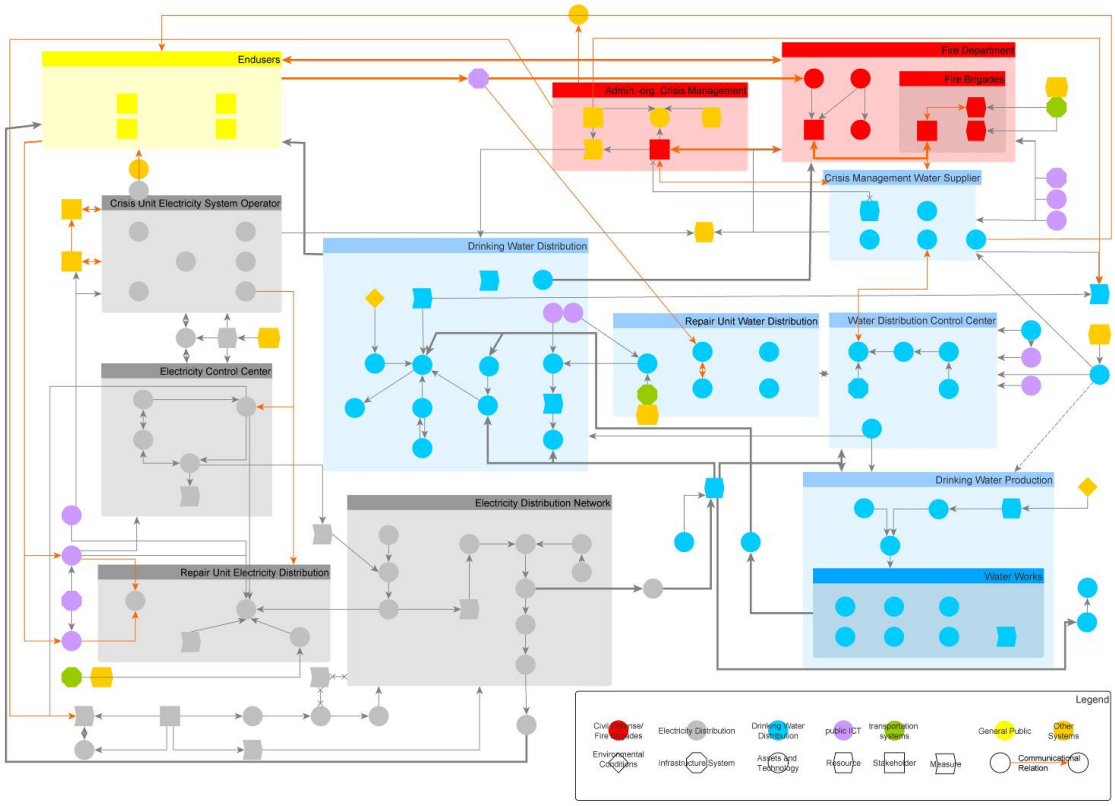


Figure 3: Schematic visualization of the processes, elements and their interdependencies in an anonymized city (Source: own figure)

Cross-Impact-Analysis: Procedure and Results

The compilation of the elements of the CI systems documents their structure and immanent processes, as well as interlinkages with each other. However, it does not help in understanding their dynamics, including their reactivity to major disturbing events and cuts in supply or information relationships. Possible cascading effects can only be assessed through a sensitivity/ cross-impact-analysis (CIA), as briefly explained above (see also (Vester, 2012; Weimer-Jehle, 2015; Heinecke, 2006). This can most practically be done by a matrix that juxtaposes system elements of the different CIs (Wilms 2006; Vester, 1991, 2012). However, as it was impossible to juxtapose each of the roughly two hundred elements (per case study) with each other, a clustering to so called "impact factors" was needed. These constitute kind of larger functional units within the systems and may embrace an entire system (such as the factors "ICT" or "flood control", see below) or even various systems (such as the factor "transportation network/ traffic"). Each of the 15 factors was defined precisely by listing up all assigned elements. This clustering allows reducing the total systemic complexity and hence gives a complete overview of the considered interdependent CI systems in the respective area/city. It visualizes the 'system of systems'.

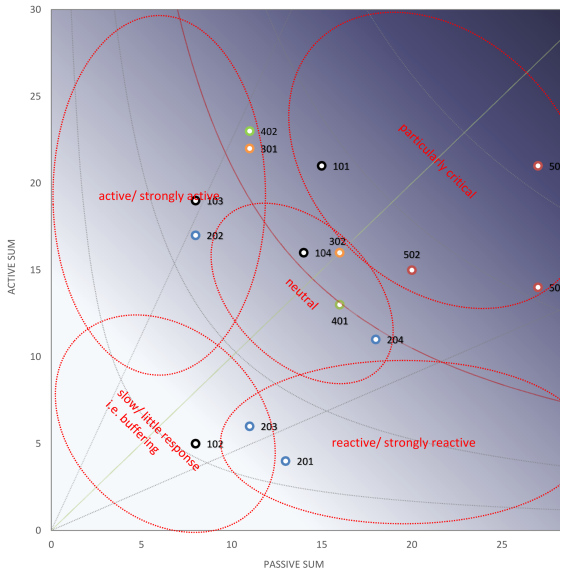
Assessing the impacts between the factors of the different CI sectors in "Cross-Impact-Matrices" followed certain rules (see Figure 4, to the left, compare Wilms 2006; Vester, 1991, 2012):

- Both defining the factors and impact assessment was done in a workshop, involving stakeholders from the concerned CI sectors, who were divided into three groups according to the three case studies. For all three different case studies, uniform impact factors were created; however, in another context, other factors might be selected and defined.
- The assessment was done under the overarching question: "What impact does a serious disturbance of the functioning of a factor have on the other factors?" The effect partly varied according to changing focus on the different elements contained in a factor. As risk analysis needs to take into account any probabilities, these have explicitly not been assessed; unlike in the original and still vastly applied CIA

approach of Gordon, Hayward (1968), Enzer (1972) and Helmer (1983) (see also Kosow & Gaßner, 2008; Weimer-Jehle, 2015; Heinecke, 2006). However, implausible effects have been ignored.

- The assessment of impact strength was done on a scale 0 = no or very low impact/ no relation, 1 = impact underproportionate/ lower than disturbance, 2 = proportionate impact, 3 = impact overproportionate/ higher than disturbance.
- Only direct impacts were considered. For example, a problem in water extraction impacted on water distribution and this in turn on the end users.
- Participants were first asked to individually assess the impacts. The reasoning behind was then explained, discussed and documented, and each impact strength was decided in a consensual manner.

Active Side \ Passive Side	101	102	103	104	201	202	203	204	301	302	401	402	501	502	503
101	x	1	1	0	2	2	2	1	2	2	1	1	2	2	2
102	2	x	2	1	0	0	0	0	0	0	0	0	0	0	0
103	2	1	x	0	1	1	1	1	2	2	1	0	2	2	3
104	3	1	1	x	0	0	1	2	0	0	0	1	2	2	3
201	0	0	0	0	x	2	2	0	0	0	0	0	0	0	0
202	1	1	1	1	1	x	1	0	1	2	2	0	2	1	3
203	0	0	0	0	2	1	x	2	0	0	0	0	1	0	0
204	0	0	0	1	0	2	2	x	0	0	0	0	2	2	2
301	1	2	0	2	0	0	0	2	x	1	2	3	3	3	3
302	0	1	1	2	0	0	1	2	0	x	0	3	3	1	2
401	1	0	0	1	1	0	0	1	1	1	x	0	3	2	2
402	1	1	1	2	3	0	0	3	1	3	2	x	2	2	2
501	2	0	0	2	2	0	1	2	2	1	3	1	x	2	3
502	1	0	0	1	1	0	0	1	1	1	3	1	3	x	2
503	1	0	1	1	0	0	0	1	1	3	2	1	2	1	x



1 Impact Factors Electricity Supply
- 101 Electricity Distribution
- 102 Grid Control and Monitoring
- 103 Grid Recovery after Blackout
- 104 Repair Management, Crisis Management, Crisis Communication

2 Impact Factors Water Supply
- 201 Water Extraction and Monitoring
- 202 Water Distribution (Network)
- 203 Distribution Network Control and Monitoring,
- 204 Repair Management, Crisis Management, Crisis Communication

3 Impact Factors Public ICT and Traffic
- 301 Public ICT
- 302 Transportation Network/ Traffic

4 Impact Factors Water Disposal and Flood Control
- 401 Communal Wastewater Disposal
- 402 Flood Control

5 Impact Factors Emergency Services/ Population
- 501 Operative Tactical Crisis Management/ Emergency Responders
- 502 Administrative Organisational Crisis Management
- 503 Demands and Commitment of End Users

Figure 4: Completed Cross-Impact-Matrix for 'Anonymized City' (left) and Criticality of Impact Factors, as a Result of the Impact Assessment (right) (Source: own figure, unassigned to any concrete city)[xix]

As a result, the total criticality of the factors is manifested in its aggregated active and passive impact scores (Figure 4, to the right). Each factor was thus located in a criticality graph with the passive sum on the abscissa and the active sum on the ordinate. Factors that are particularly sensible have both high active and passive sums, highlighting particular 'critical nodes' in the system, while factors with low sums are rather slowly reacting or buffering. However, even the latter may be important in singular cases for further cascading effects. Possible second, third and fourth order cascading effects can be shown through further analytical steps of impact chain analysis.

Combination of Qualitative and Quantitative (GIS) Analysis

While the above steps helped selecting particularly sensitive or critical nodes within the entire system of systems, the performed GIS analysis was then used to a) map the selected elements and zoom into the respective

interdependencies and b) identify critical nodes and interdependencies that had been overseen in the qualitative analysis. An extreme flood scenario was chosen for GIS simulation. To show the possible impacts of the flood, the following figure visualizes selected elements of different CIs (fuel stations, emergency response and electricity distribution assets) exemplarily for the city of Cologne, using OS data and non-sensitive information (Figure 5).

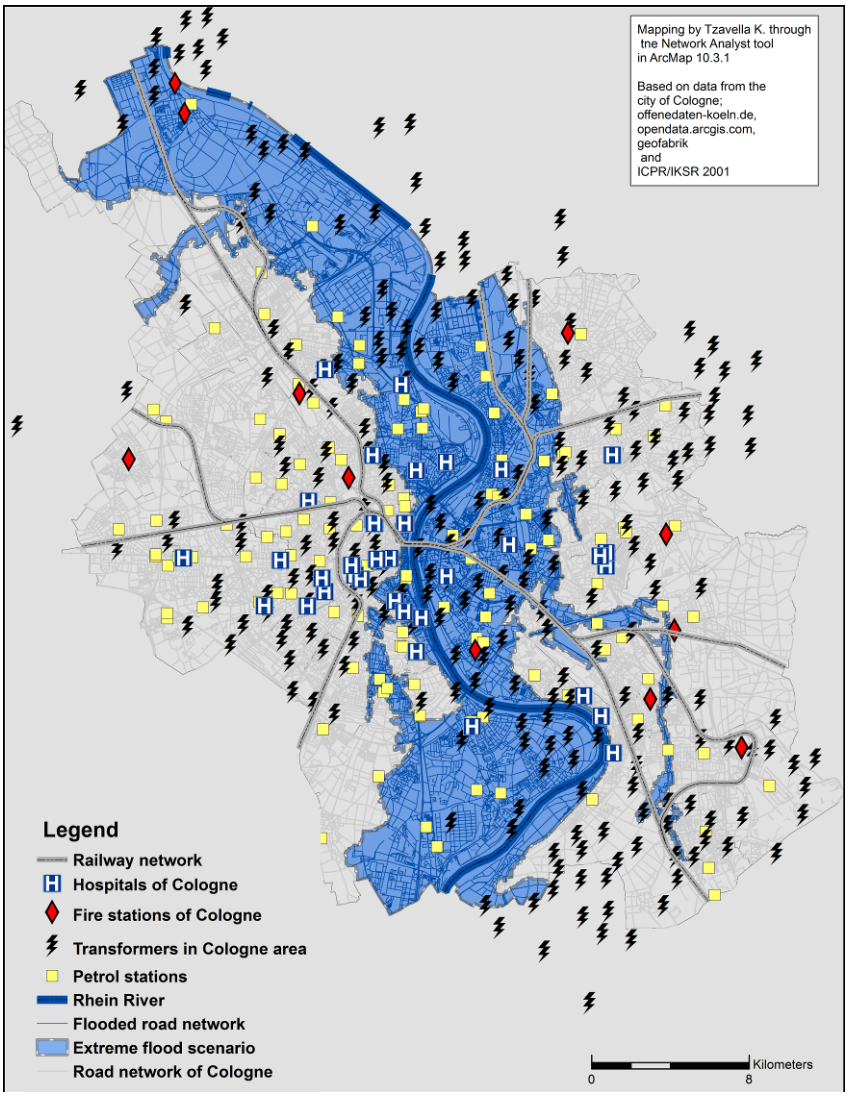


Figure 5: Different CIs of the city of Cologne affected by the extreme flood scenario (Source: own figure using open source data)

First of all, in Figure 5, the spatial exposure assessment of the different CIs to an extreme flood scenario reveals their geographical interdependency, as various CIs are exposed to flood at the same time. Furthermore, the map points to dependency of some of the above-mentioned elements (e.g. repairing activities and emergency response/firefighting) on the transportation network, fuel supply, and electricity supply. In this way, the result of the cross-impact-analysis was verified, even showing that the impact might have been underestimated given the geographical interdependency. The identification of such geographical interdependencies and their integration into an emergency response plan has been covered in detail in Tzavella et al. (2017). From the above results of the qualitative analysis steps, it was further derived that traffic is a critical impact factor and should be taken into consideration in repairing management, for operative-tactical emergency/crisis management and for flood control.

In order to test these results and get a more precise understanding of their implications for a distinct scenario, GIS data on traffic density (high road network density and high traffic lights density) was combined with the location of transformers and the flooded areas. This yielded precisely, which transformers need to be disconnected due to flooding, and thus which roads, traffic lights and intersections are most critical or – on the other hand – which ones would presumably not be as much affected as it seems from the more general qualitative analysis. Thus, effects on response and repairing time (of emergency responders and critical infrastructure repair management) can be calculated and alternative routes considered. In Figure 6, it is shown that some transformers are located in the flooded area. Emergency managers can use such information for planning repair times, considering contraints such as the driving time through flooded road networks (Fekete et al., 2016; Tzavella et al., 2017).

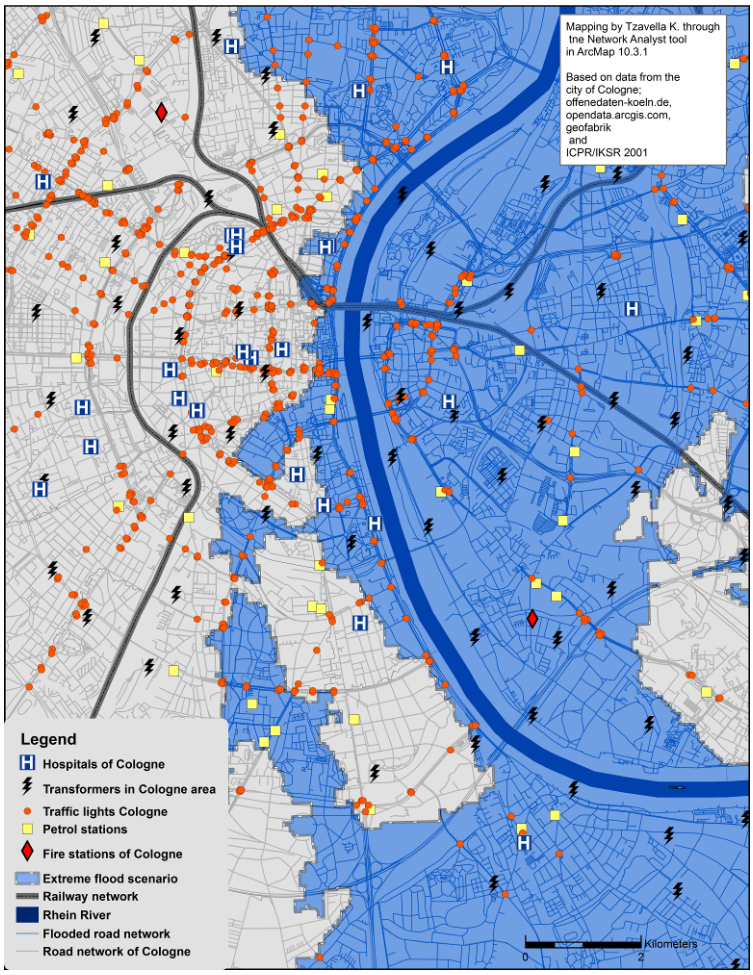


Figure 6: Critical infrastructures of Cologne affected from the flood including the traffic lights (Source: own figure using open source data)

Additionally, further **physical interdependencies** can be identified using GIS. The road and the railway networks are physically interdependent when sharing physical structure such as bridges. As observed, all the trains approaching Cologne are following railway lines that are crossing major road network segments. A bridge can also carry water lines, IT and gas lines. A failure in these areas could indicate a cascading effect of failures in the day-to-day functionality of the city.

The identification of these physical interdependencies and the information that is provided regarding the potential cascading effects mentioned above, could only be addressed through the quantitative analysis with GIS visualizations of datasets, as they had not been identified before by the stakeholders during the phase of qualitative analyses. Also, the results of GIS analysis displayed interdependencies that were implied and "hidden" in combinatory nodes between the different interdependent elements and were unidentified through the

qualitative analysis. This identification of the CI at risk adds value to the situational awareness phase of the emergency management, leading to a timely effective emergency response.

Additional information yielded by the quantitative analysis can be fed back into the cross-impact-analysis, and of course the preliminary system analysis. It can thus provide supplemental and more precise information for rethinking the sensitivities between the impact factors.

DISCUSSION: POTENTIALS AND CHALLENGES OF PARTICIPATORY QUALITATIVE-QUANTITATIVE ANALYSIS

The applied approach brings about the advantage of capturing experiences and subjective opinions of the participating stakeholders and experts, allowing them to indicate the most critical aspects and challenges they face in preparing possible supply disruptions. Compared to the existing recent methods of EU research projects discussed in the literature review, this method has a similar orientation, given its interdisciplinary and participatory character, but offers a viable solution to the challenge of data acquisition and management.

Specific Methodologic Advantages and Limitations

In comparison to preceding work, the approach disposes of three major advantages: It

i) allows for assessing the interdependencies between various systems and actors at the local level and thus serves as an iterative informational/advisory system for the decision makers,

ii) does not demand precise data sets from the participants, thus avoiding the often-insurmountable obstacle of sensitive data sharing or even costly data collection (Garcia-Aristizabal et al., 2015), and yet

iii) provides relevant information both in specific detail (combined qualitative description of key elements and analysis of their nodes and quantitative GIS analysis), as well as on a more abstract but all-embracing level (cross-impact-analysis using aggregated impact factors), thus drawing the entire picture.

The approach therefore serves as an ideal basis for further processing of information, e.g. in building reliable scenarios, or building up a systematized geo-databases (see e.g. Herrera et al., 2015). In particular, it can serve for providing an appropriate informational basis for interorganizational crisis communication and joint situation analysis tools, such as AlphaKomm (Töppel et al., 2017) or its predecessor SIMKAS-3D. However, even though the system and cross-impact, as well as geospatial analyses can be performed in detail for the interconnections between different (sub-)systems, it will only be able to serve as an important informational basis for a general understanding of the functionality of systems and their embeddedness, and for local or regional crisis-scenario-analysis. Further data-based and detailed analysis is still needed when it comes to precisely understanding technical interfaces.

The Challenge of Involving Practitioners and Exchanging Information

The chosen format of interviews and workshop discussions helped to prioritize information dialectically together with the experts. For critical system nodes and (inter)dependencies, more detailed information was gathered. Contrasting or even contradicting expert opinions could be discussed right away. On the other side, much of the subjective information gained from the experts needed to be cross-checked with other expert statements and information from existing research or other reliable sources. Concerning particularly the GIS analysis, plausibility checks through the involved experts allowed for valuable outcomes even from analyses based on lower quality open source data.

Initially, the participatory procedure faced the challenge of building trust between the involved experts and the researchers. As it demanded much time from the former to provide the needed information in workshops and interviews, they showed a certain initial skepticism. This however vanished at the point when they more clearly saw the direct benefit for themselves, namely, to exchange information about mutual dependencies and weaknesses for the first time outside of specific exercises or formal frameworks. CI operators and emergency responders recognized that they have had contrasting expectations or an incomplete understanding of service availability of the other CIs in crisis situations beforehand. They turned out to be willing to providing insights into dependencies and crisis management of their companies.

During focus group discussions, the associated partners and other potential users were repeatedly shown demonstrators of the interdependency and GIS assessments and interview results. They were asked not only to give feedback on possible improvements, but also to indicate further demands and type of documentation so they could benefit from the results. The stakeholders confirmed their usefulness e.g. in terms of i) justification of their work on security and emergency management, ii) intensifying the CIRMin-triggered knowledge exchange parallel and even after the end of the project (in bilateral collaborations) and iii) applying GIS planning instruments for emergency back-ups and resource planning.

CONCLUSION AND OUTLOOK

The interdependency analysis presented here offers several advantages, namely that it provides a way to understanding how different CI systems function i) separately (identification of system structures within each sector) and ii) in interaction (intersectoral interdependencies). Based on qualitative information and analysis, it captures not only the structure, but also the dynamic between technical, social, and communicative elements of the CI systems. This is important for being able to adopt effective resilience-building (Kröger, 2012). The combination of qualitative and GIS (quantitative) interdependency analysis yielded a comprehensive overview of what measures are needed for coping with possible disruptions and maintaining the functionalities of CI in crisis situations. It points out to indispensably needed resources for CI operation, redundancies in the supply networks and auxiliary powers, and gives hints how to optimize repairing activities, crisis management and response time. Also, in the particular research context, the documented approach helped identifying critical elements and impact factors that are relevant for providing minimal (or reduced) supply for the population. Such provision can enhance the resilience of the population to specific risks, since a thorough crisis preparation allows for a quicker bounce back to normal.

As an add-on to the documented analytical work and subject to further research, cascading effects may be visualized in the form of risk maps, showing the affected elements and their risk level to fail. This would require further spatial analyses, classifications and weighting of criticality levels, as well as a categorization of processes according to geographical relations. The resulting maps would finally provide an aggregated criticality level of the different elements per area.

Even though CI systems inside and outside of cities differ in detail, their main structures, processes and interdependencies show similarities. The presented methodological approach can hence be transferred to other areas, by some limitations: Firstly, the authors are at the same time involved as observers and participants in such a participatory approach (Fekete, 2012b). This limits their abilities to recognize certain constraints. Secondly, all case studies are located within the same region. Nonetheless, if key conditions are comparable, transferability should be possible to other German regions and even into other countries. Thirdly, readiness for co-creating knowledge is the decisive factor for applying the approach presented here.

ACKNOWLEDGEMENT

CIRMin is funded by the German Ministry of Education and Research (BMBF) from 6/2016 to 5/2019 in the context of the research program "Zivile Sicherheit – Erhöhung der Resilienz im Krisen- und Katastrophenfall".

REFERENCES

Bach, C., Bouchon, S., Fekete, A., Birkmann, J. and Serre, D. (2013) Adding Value to Critical Infrastructure Research and Disaster Risk Management. The Resilience Concept, *S.A.P.I.EN.S,* 6(1), 1-12.

Bagheri, E. and Ghorbani, A.A. (2008) The state of the art in critical infrastructure protection: a framework for convergence, *International Journal of Critical Infrastructures,* 4(3), 215 - 244.

Baloye, D. and Palamuleni, L. (2016) Modelling a critical infrastructure-driven spatial database for proactive disaster management: a developing country context, *Jàmbá - Journal of Disaster Risk Studies,* 8(14), 8(1), a220. http://dx.doi.org/10.4102/jamba.v8i1.220.

Barthe-Delanoë, A.-M., Trupti, S. and Bénaben, F. (2015) Towards a taxonomy of crisis management simulation tools, In Palen, L., Büscher, M., Comes,T. and Hughes, A. (Eds.) *Proceedings of the ISCRAM 2015 Conference - Kristiansand, May 24-27.*

Bloomfield, R., Chozos, N., and Nobles, P. (2009) Infrastructure interdependency analysis: Requirements, capabilities and strategy, Adelard LLP, London, UK.

Brennan-Horley, C. and Gibson, C. (2009) Where is creativity in the city? Integrating qualitative and GIS methods, *Environment and Planning*, 41, 2595-2614.

Clarke, L. (1999) Mission improbable: Using fantasy documents to tame disaster, The University of Chicago Press, Chicago/ London.

Dierich, A., Schön, S., Bartels, M., Hahne, M., Hempel, L. and Lieb, R. (2012) Szenarioanalyse für intersektorales Infrastruktur-Management, *energie | wasser-praxis*, 6, 20-23.

Dudenhoeffer, D. and Permann, M. (2006) CIMS: A Framework for Infrastructure Interdependency Modelling and Analysis, In Perrone, L. F., Wieland, F.P, Liu, J, Lawson, B.G., Nicol D.M. and Fujimoto, R.M. (Eds.) *Proceedings of the 2006 Winter Simulation Conference. The 2006 Winter Simulation Conference, Monterey, CA, USA, 3.-6. Dez 2006*, 478–485.

Enzer, S. (1972) Cross-Impact Techniques in Technology Assessment, *Futures* March 1972, 30-51.

European Commission (2008) Council Directive 2008/114/ Ec of 8 December 2008 on the Identification and Designation of European Critical Infrastructures and the Assessment of the Need to Improve Their Protection, *Official Journal of the European Union*, 23.12.2008, L 345/75-82.

Faturechi, R, and Miller-Hooks, E. (2015) Measuring the performance of transportation infrastructure systems in disasters: a comprehensive review, *J Infrastruct Syst*, 21(1), 04014025

FMIG - Federal Ministry of the Interior of Germany (2009) National Strategy for Critical Infrastructure Protection (CIP Strategy), Berlin.

Fekete, A. (2012a) Spatial Disaster Vulnerability and Risk Assessments: Challenges in Their Quality and Acceptance, *Natural Hazards,* 61(3), 1161-78.

Fekete, A. (2012b) Safety and Security Target Levels: Opportunities and Challenges for Risk Management and Risk Communication, *International Journal of Disaster Risk Reduction,* 67-76.

Fekete, A., Tzavella, K. and Baumhauer, R. (2016) Spatial exposure aspects contributing to vulnerability and resilience assessments of urban critical infrastructure in a flood and blackout context, *Natural Hazards*, 1-26.

Fekete, A., Tzavella, K. and Baumhauer, R. (2017) Spatial Exposure Aspects Contributing to Vulnerability and Resilience Assessments of Urban Critical Infrastructure in a Flood and Blackout Context, *Natural Hazards,* 86(1), 151-76.

GAR (2015) Global assessment report on disaster risk reduction, UNISDR.

Garcia-Aristizabal, A., Zuccaro, G., Aubrecht, C., Polese, M. and Almeida, M. (2015) Improving emergency preparedness with simulation of cascading events scenarios, In Palen, L., Büscher P.; M., Comes, T. and Hughes, A. (Eds.) *Proceedings of the ISCRAM 2015 Conference - Kristiansand, May 24-27*.

Gordon, T., & H. Hayward (1968): Initial Experiments with the Cross Impact Matrix Method of Forecasting. In: *Futures 1(2)*, pp. 100–116.

Grafenauer, T., König, S., Rass, S. and S. Schauer (2018) A simulation tool for cascading effects in interdependent critical infrastructures. In Proceedings of the 13th International Conference on Availability, Reliability and Security (ARES 2018). ACM, New York, NY, USA,

Giannopoulos, G., Filippini, R. and Schimmer, M. (2012) Risk assessment methodologies for Critical Infrastructure Protection. Part I: A state of the art*, Joint Research Centre – Institute for the Protection and Security of the Citizen. Luxembourg*, Publications Office of the European Union, Luxembourg.

Heinecke, A. (2006) Die Anwendung induktiver Verfahren in der Szenario-Technik. In Wilms, F.E.P. (Ed.) Szenariotechnik. Vom Umgang mit der Zukunft, Haupt, Berne, Switzerland, 183-213.

Helmer, O. (1983) Looking Forward. A Guide to Futures Research, Sage Publications, Beverly Hills, CA, USA.

Herrera, M., Batista e Silva, F., Bianchi, A., Barranco, R. and Lavalle, C. (2015) A geographical database of Infrastructures in Europe. A contribution to the knowledge base of the LUISA modelling platform. *Joint Research Center, European Union*, Brussels.

Hokstad, P., Utne, I. B., and Vatn, J. (2012) Interdependency Modelling in Risk Analysis. In Hokstad, P., Utne, I. B., and Vatn, J. (Eds.) *Risk and Interdependencies in Critical Infrastructures. A Guideline for Analysis,* Springer, London, 2012, 35-48.

inter 3 - Institut für Ressourcenmanagement (2013) *Simkas 3D:* Simulation von intersektoriellen Kaskadeneffekten bei Ausfällen von Versorgungsinfrastrukturen unter Verwendung des virtuellen 3D-Stadtmodells von Berlin*,* Teilvorhaben: Untersuchung sektoriell übergreifender Szenarien; Abschlussbericht, Technische Informationsbibliothek Hannover, Hannover.

Kosow, H. & Gaßner, R. (2008) Methoden der Zukunfts- und Szenarioanalyse. Überblick, Bewertung und Auswahlkriterien. WerkstattBericht Nr. 103, IZT – Institut für Zukunftsstudien und Technologiebewertung Berlin. https://www.izt.de/fileadmin/downloads/pdf/IZT_WB103.pdf.

Kröger, W. (2012) Understanding Complexity and Interdependency: A prerequisite to increase resilience, In G. Giannopoulos, G. and Filippini, R. (Eds.) *Risk Assessment and Resilience for Critical Infrastructures. Workshop Proceedings 25-26 April 2012, Ranco, Italy*, 41-52.

Kwan, M. and Knigge, L. (2006) Doing qualitative research using GIS: An oxymoronic endeavor*?, Environment and Planning A*, 38, 1999-2002. 10.1068/a38462.

Lenz, S. (2009) Vulnerabilität Kritischer Infrastrukturen, In Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (Eds.) *Forschung im Bevölkerungsschutz, Band 4,* Bonn.

Little, R.G. (2002) Controlling Cascading Failure: Understanding the Vulnerabilities of Interconnected Infrastructures, *Journal of Urban Technology*, 9(1), 109–123.

López-Silva, J., Bañuls, V.A. and Turoff, M. (2015) Scenario Based Approach for Risks Analysis in Critical Infrastructures. In Palen, L., Büscher P.; M., Comes, T. and Hughes, A. (Eds.) *Proceedings of the ISCRAM 2015 Conference*, Kristiansand.

Malik Management Zentrum St. Gallen (2014) Malik Sensitivity Model®Prof. Vester: The Computerized System Tools for a New Management of Complex Problems, St. Gallen.

Mansor, S., Mohammed, A.S., Lawal, B., Iwan, S. and Faisal, J. (2004) Spatial technology for natural risk management, *Disaster Prev Manag,* 13(5), 364–373.

O´Rourke, T. D. (2007) Critical Infrastructure, Interdependencies, and Resilience, *The Bridge - Linking Engineering and Society,* 37(1), 22–29.

Ouyang, M. (2014) Review on modeling and simulation of interdependent critical infrastructure systems, *Reliability Engineering & System Safety,* 121, 43–60. DOI: 10.1016/j.ress.2013.06.040.

Pederson, P., Dudenhoeffer, D., Hartley, S. and Permann, M. (2006) Critical Infrastructure Interdependency Modelling: A Survey of U.S. and International Research, Idaho National Laboratory, Idaho Falls, Idaho.

Perrow, C. (1984). *Normal accidents*, Basic Books, New York, NY.

Petermann, T., Bradke, H., Lüllmann, A., Poetzsch, M. and Riehm, U. (2010) Gefährdung und Verletzbarkeit moderner Gesellschaften – am Beispiel eines großräumigen Ausfalls der Stromversorgung (Endbericht zum TA-Projekt. Arbeitsbericht Nr. 141), Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, Berlin.

Petit, F., Wallace, K. und Phillips, J. (2014) An Approach to Critical Infrastructure Resilience, *The CIP Report, Center for Infrastructure Protection and Homeland Security*, George Mason University School of Law Washington D.C., 12(7), 17–20.

Petit, F., Verner, D., Brannegan, D., Buehring, W., Dickinson D., Guziel, K., Haffenden, R., Philips, J. and Peerenboorn, J. (2015) Analysis of Critical Infrastructure Dependencies and Interdependencies. Argonne National Laboratory, Technical Report N° ANL/GSS-15/4111906, Argonne, US.

Pfeffer, K.., Martinez, J., Baud, I. and Sridharan, N. (2011) Knowledge Production in Urban Governance Systems through Qualitative Geographical Information Systems (GIS), *Environment and Urbanization ASIA*, 2(2), 235-250.

Reissberg, A. C. (2012) Managing natural catastrophies: Viable Systems to prevent human tragedy - the Hawai'ian example, Campus Verlag, Frankfurt a.M., Germany.

Rinaldi, S. M., Peerenboom, J. P. and Kelly, T. K. (2001) Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies, *IEEE Control Systems Magazine,* December 2001, 1–25.

Robert B, Morabito, L., Cloutier, I. and Hémond, Y. (2015) Interdependent critical infrastructures resilience: Methodology and case study, *Disaster Prevention and Management*, 24(1), 70-79.

Schätter, F., Wiens, M., Meng, S. and Schultmann, F. (2014) A multi - stage scenario construction approach for critical infrastructure protection, In Hiltz, S.R., Pfaff ,M.S., Plotnick, L, and Shih, P.C (Eds.) *Proceedings of the 11th International ISCRAM Conference, Pennsylvania, USA, May 18-21, 2014*, 399–408.

Töppel, M., Hahne, M. and Bartels, M. (2017) Informationsvorlagen für die interorganisationale Kommunikation im Krisenfall, *Crisis Prevention*, 1/2017. https://crisis-prevention.de/feuerwehr-katastrophenschutz/informationsvorlagen-fuer-die-interorganisationale-kommunikation-im-krisenfall

Turoff, M.; Bañuls, V.A.; Plotnick, L.; Hiltz, S.R. (2014) Development of a Dynamic Scenario Model for the Interaction of Critical Infrastructures, In Hiltz, S.R., Pfaff ,M.S., Plotnick, L, and Shih, P.C (Eds.) *Proceedings of the 11th International ISCRAM Conference, Pennsylvania, USA, May 18-21, 2014*, 414-423.

Tzavella, K., Fekete, A. and Fiedrich, F. (2017) Opportunities provided by geographic information systems and volunteered geographic information for a timely emergency response during flood events in Cologne, Germany, *Natural Hazards* (2018) 91(Suppl 1): 29. https://doi.org/10.1007/s11069-017-3102-1

US Government (1996) The President's Commission on Critical Infrastructure Protection (Pccip), Executive Order 13010, Washington, DC.

Utne, I. B., Hokstad, P. and Vatn, J. (2011). A method for risk modeling of interdependencies in critical infrastructures, *Reliability Engineering & System Safety,* 96 (6), 671–678. DOI: 10.1016/j.ress.2010.12.006.

Vester, F. (2012) Die Kunst vernetzt zu denken. Ideen und Werkzeuge für einen neuen Umgang mit Komplexität. Ein Bericht an den Club of Rome, 9. aktualisierte Ausgabe, DTB, Munich, Germany.

Vester, F. (1991) Ausfahrt Zukunft Supplement. Material zur Systemuntersuchung, Studiengruppe für Biologie und Umwelt GmbH, Munich, Germany.

Vester, F. (1988). The Biocybernetic Approach as a Basis for Planning Our Environment, *Systems Practice*, 1(4), 399-413.

Weimer-Jehle W. (2015) Cross-Impact-Analyse. In: Niederberger M., Wassermann S. (Eds) Methoden der Experten- und Stakeholdereinbindung in der sozialwissenschaftlichen Forschung. Springer VS, Wiesbaden, 243-258.

Wilms, F.E.P. (2006) Szenarien sind Systeme. In ibid (Ed.) Szenariotechnik. Vom Umgang mit der Zukunft, Haupt, Berne, Switzerland, 39-59.

[i] https://cordis.europa.eu/project/rcn/88359_en.html
[ii] http://www.after-project.eu/Layout/after/
[iii] http://www.tanknotstrom.de/
[iv] https://www.bbk.bund.de/DE/Service/Fachinformationsstelle/Informationsangebote/Forschungsberichte/ForschungKritischeInfrastrukturen/Energie/MIA/MIA_node.html
[v] http://www.strest-eu.org/
[vi] http://www.smartresilience.eu-vri.eu/
[vii] https://www.unibw.de/wasserwesen/swa/nowa
[viii] https://www.kontikat.de/
[ix] http://casceff.eu/publications/
[x] http://www.predict-project.eu/about-0
[xi] http://www.driver-project.eu/
[xii] http://www.crismaproject.eu/
[xiii] http://snowball-project.eu/outputs/
[xiv] https://cordis.europa.eu/result/rcn/182552_en.html
[xv] https://pro.arcgis.com/en/pro-app/help/data/data-interoperability/spatial-etl-tools.htm
[xvi] https://www.geofabrik.de/en/
[xvii] http://www.offenedaten-koeln.de/
[xviii] http://www.iksr.org/
[xix] In this modified and unassigned example cross-impact-matrix, (external) electricity generation and supply has been omitted, as it is not under control of the anonymous city.

Choosing Optimal Ways to Increase Resilience of Critical Infrastructures

Sandra König
Austrian Institute of Technology
Sandra.Koenig@ait.ac.at

ABSTRACT

Increasing resilience is a core interest in critical infrastructure (CI) protection that involves many challenges. It is necessary to agree on a common understanding of resilience and identify potential strategies to improve it. Once this is done, the question arises how to choose among these strategies. We propose to decide based on a game-theoretic framework that allows identification of optimal actions under various scenarios. This framework considers different threat scenarios as attacks to the CI and the identified strategies to improve resilience as defense strategies for the CI. Since the payoff of the game, namely the resilience of the CI, can hardly be measured with certainty we choose an extension of classical game theory that allows taking uncertainty into account and still finds provably optimal solutions. This approach is especially useful in a situation where we aim to optimize a quantity that is difficult to measure (such as resilience). The result of this analysis is two-fold: it identifies an optimal defense but also provides information about the resilience in the worst case. The approach is illustrated with a small example using a publicly available implementation.

Keywords

Resilience, critical infrastructure, optimization, game theory.

INTRODUCTION

In the context of critical infrastructures (CIs) resilience is especially important as the impact of a failure or even limited availability of a CI has a significant impact on society and economy (Boumphrey and Bruno 2015; National Infrastructure Commission 2017; Royal Academy of Engineering 2018). Several measures for resilience exist for specific sectors of CIs, e.g., for the energy domain (Panteli et al. 2017) or the water supply (Cuisong and Hao 2008), or for specific scenarios, e.g., for hurricanes (Tokgoz and Gheorghe 2013). More advanced approaches to resilience take into account viewpoints from organizations and people (Gouglidis et al. 2016) but are more time-consuming to evaluate. In this work, we use a more general formulation of resilience in the context of CIs to develop a general methodology that may be refined for specific sectors. We choose a more general measure as proposed in (König et al. 2019) that is simple but in line with a risk management process according to ISO 31000. This measure builds on the notion of risk as the product of likelihood and impact by defining the resilience against a specific scenario as the product of likelihood and a factor depending on the expected impact due to the risk scenario and the preparedness against it. It is constructed in such a way that positive values indicate that preparedness is on average higher than the expected damage and negative values indicate that preparedness is not sufficient on average.

Once agreed on a measure for resilience, the aim is to identify ways to improve it as much as possible. This involves several challenges. First, it is important to identify relevant threats and potential countermeasures. Then, the question is which of these countermeasures should be chosen to optimize resilience. Answers to the first question are manifold and may include consultation of vulnerability databases but also adversary modelling. Still, such a list of threats will always be incomplete due to the risk of unexpected events (i.e., black swans). The second question on the other hand may be threated rigorously by applying optimization techniques. As the resulting resilience depends on both the threat and the countermeasure we here apply a game-theoretic framework where an attacker causes problems that reduce the CI's resilience while the CI operator tries to maximize the resilience in the light of all possible attack. In this somewhat abstract view the attacker is not necessarily a real person but anything that threatens the CI, including nature. In this setting it is impossible to model

the adversary explicitly since we do not have any information on his intention. However, considering the worst case that the adversary's intentions are exactly opposite to the defenders ones (i.e., playing a zero-sum game) provides a lower bound to the resilience if the CI. This game theoretic optimization of resilience may benefit from existing risk management processes where for example risks have been identified and evaluated. Such information may be incorporated in the described approach.
This paper is structured as follows. After a discussion on how to measure resilience in CIs we focus on ways to improve it based on the proposed game theoretic framework. This consists of the identification of threat scenarios and strategies to improve resilience as well as estimation of the resilience for each scenario to build a game. The choice on an optimal improvement strategy is found by solving this game. An example is provided to illustrate how to apply the theoretic model. Open issues are discussed in the conclusion.

MEASURING RESILIENCE IN CRITICAL INFRASTRUCTURES

When aiming for improvement of resilience, it is necessary to have a measure of resilience so that different situations can be compared. While a general definition is hard to find, formalizations are possible for specific fields. Concerning CIs, the term resilience can be understood (analogously to the term risk) as

$$R = \sum_{s=1}^{N} \omega_s \cdot (P_s - E\,[I_s]), \qquad (*)$$

where the sum is over all scenarios s, ω_s is the likelihood of occurrence of scenario s, P_s is the preparedness against scenario s, and $E\,[I_s]$ is the expected impact on the CI in case scenario s happens (König et al. 2019). In order to compute this value, it is first necessary to agree on a set of scenarios that threaten the CI. These include both natural disasters and intentional attacks. For each of these scenarios it is then necessary to estimate the likelihood of occurrence, which is often based on historical data about similar events. Then, every single scenario needs to be investigated to answer two questions:

- What is the expected impact on the CI for this scenario?
- How well is the CI prepared for this scenario in the sense that it is able to keep its functionality to a certain level despite a realization of the scenario?

If available, simulation methods may be used to mimic a scenario and estimate its impact. Otherwise, experts may be able to provide a qualitative estimate or historical data may be available. The second question is a bit more difficult to answer as the term preparedness is not clearly defined, but needs to be taken into account (Martin and Ludek 2013). Practically, it is necessary to measure expected impact and preparedness on the same scale to be able to evaluate formula (*) above. A qualitative scale, e.g., a 5-tier scale, is recommended for experts' opinions since precise estimations are difficult to get. In that case, the term *preparedness level* is used. In the context of CI resilience, the term preparedness is understood as the maximal degree of impact that still allows smooth operation (similar to the breaking point of an estimator in statistics), i.e., a damage higher than the preparedness yields to limited functionality of the CI and reduces the overall resilience of the CI (as this scenario contributes a negative value to the sum).

When investigating resilience of a CI it is not always enough to have a single value that provides an average resilience. A deeper analysis may be concerned about the various scenarios and their severity. In particular, we aim to identify scenarios with the low resilience as these threaten the system the most. Thus, we focus on the resilience R_s for a specific scenario s,

$$R_s = \omega_s \cdot (P_s - E\,[I_s]),$$

to be able to compare the different situations. The value is also influenced by changes in the CI, in particular if different strategies for improvement are implemented. For a bunch of improvement strategies we identify those that are optimal, i.e., that reduce resilience the most.

INCREASING RESILIENCE OF A CRITICAL INFRASTRUCTURE

Evaluation of the resilience for the current situation is only the first step in an analysis that aims at improving resilience of a CI. Consider a fixed set of scenarios with known probabilities of occurrences. When applying the formulation of resilience as described above, resilience can be improved by either increasing the preparedness level or reducing the expected impact (or even both at the same time).

Potential strategies for improvement range from implementation of new protection measures (e.g., honeypots to detect malware), improving existing controls (e.g., check pumps more frequently) or training of employees to increase awareness of new threats. While a list of potential actions can be found in discussion with experts, it is

typically not possible to apply all potential actions due to limited resources. The challenge is then to decide which strategies should be chosen. In this work, we apply a game-theoretic framework that describes a threat to a CI as an attack (intentional or not) while the CI operator is in the position to defend, i.e., to protect his system. As we do not have any knowledge on the attackers intentions (especially in the case of natural disasters), we model the situation with a zero-sum game that assumes an adversary who tries to cause as much damage as possible while the defender tries to minimize the suffered damage. Analysing the situation with this approach consists of three steps:

(1) identification of threat scenarios
(2) identification of countermeasures
(3) estimating resilience for each combination of an attack and defence (a scenario)

Threat scenarios are interpreted as attack strategies where the attacker does not need to be a person but also nature, basically anything that causes harm to the CI. Similarly, countermeasures are interpreted as defence strategies since these help reducing the expected damage. Finally, the estimated resilience is the payoff that the defender cares about. He aims to maximize it while the attacker's actions aim at reducing it. In the remainder of this section we elaborate on these three steps.

Identification of Threats and Countermeasures

The identification of relevant threats to the CI and potential countermeasures to protect the system is the most difficult part of the game-theoretic analysis. A game-theoretic equilibrium identifies the worst-case attack and the best way to protect against it, but it can only be chosen from available information. The optimality of the found solution is no longer valid if attacks have not been considered or defence strategies are incomplete or cannot be applied in practice. A list of threats contains information on past incidents as well as issues identified with experts familiar with the system. Recent publications such as (Ghafir et al. 2018; Zimba et al. 2018) describe various scenarios that may harm the system.
A list of countermeasures has at least two sources of information: international standards such as ISO27001 and expert knowledge. Additional actions that may protect the system can be found when analysing past incidents or penetration testing, but also from publications such as (Walker-Roberts et al. 2018). Further, a list of threats may be available form a classical risk analysis that includes risk identification and evaluation. Despite all these different sources, the list of threats will always be incomplete (as it misses for example unexpected events). However, this is a general issues and not a weakness of the game theoretic approach. Another issue is the growth of the strategy space when combinations of attacks are considered. While this is a problem in the theoretical setting it is not such a big issue in practical applications as combination of threats (e.g., a contamination followed by an earthquake) are rather rare and arbitrary combination of protection measures may not be affordable for the CI operator.

Estimation of Resilience

Having a set of relevant attacks and feasible defence strategeis, resilience must be estimated for each scenario. For the resilience measure used here this requires estimation of the expected impact and the preparedness for a specific attack and a fixed countermeasure. The likelihood of occurrence remains the same (just as the chances of a lightning when computing the risk), but countermeasures influence the impact of a scenario (i.e., better protection prevents the house from burning down). Different strategies typically do not change the dynamics of the cascading effects but rather cause a faster or slower spreading. In case the expected impact is estimated based on simulations, different scenarios may be analysed by choosing different parameters for the simulation. In case we are not able to mimic the consequences of an attack, we need to ask experts to rate the expected damage. In both cases, we get several estimates for the same situation which yields distribution-valued payoffs. As described above, preparedness is measured through expert assessments on a qualitative scale. Also, this estimate is distributions-valued if we ask several experts for their assessment and do not aggregate their assessments.
In a classical game-theoretic setting, the estimated payoffs need to be real numbers but extensions allow payoffs to be random variables (Rass et al. 2015). This allows in particular dealing with disagreement among experts since it is not necessary to agree on a single estimate. Rather, we collect all available opinions and work with histograms instead of numbers. While this may yield pessimistic estimates (e.g., if one of the experts tends to be anxious) it is in line with a qualitative risk assessment as recommended by the German Federal office of Information Security (BSI). Further, this general approach helps to keep track of single assessments and thus increases the understanding of the decision while such information is lost if different opinions are aggregated.

Choosing Optimal Protection Strategy

In order to find an optimal protection strategy the game needs to be solved. Since our estimate of resilience contains assessments from several experts we apply the more general setting. It allows taking into account every single assessment rather than aggregating all these different opinions. Even in this generalized setting a Nash equilibrium can be computed (Rass et al. 2016) with the (generalized) fictitious play algorithm. It mimics a fixed number of game plays and records how often each strategy has been played. It can be shown that this yields an estimate of a Nash equilibrium (Rass et al. 2016) where no player has an incentive to deviate since he will not be able to improve. An implementation of the methods applied here is publicly available on CRAN (Rass and König 2018). Its use is illustrated with a small example below.
The main difference to existing approaches lies in the way how uncertainty is taken into account. Stochastic models like Bayesian games assume that a player is unsure about what type of adversary he is playing with but is certain about the payoffs in each possible case. Our point of view is different: we think it is generally very changing to exactly predict the payoffs for a given scenario which is why we replace the crisp (real-valued) payoff by a random variable.

ILLUSTRATIVE EXAMPLE

Consider a fictitious water provider that uses an industrial control system such as a SCADA (Supervisory Control and Data Acquisition) system to control its processes. The SCADA server as the central component of the SCADA network is located in a control room to allow monitoring processes in real time. Programmable Logic Controllers (PLCs) supervise processes at the treatment plant and Remote Terminal Units (RTUs) at remote sites such as pump stations.

The game-theoretic model considers the three attacks

- s_1 contamination
- s_2 earthquake
- s_3 attack on SCADA system

and the defence strategies

- d_1 more water reservoirs
- d_2 more frequent controls

Attacks on SCADA systems are manifold. We here consider the situation where data in the SCADA system are manipulated in such a way that a change at the remote site is not recognised or such that fake data provokes an act that causes damage to the system.
Increasing the amount of stored water in reservoirs aims at reducing the damage in case of a contamination. Regular controls help to detect problems with the water quality (e.g., due to a contamination) as well as a potential mismatch between the real status of a site and the data reported by the SCADA system in case of an attack that involves forged data. Countermeasures against earthquakes are complex and expensive (e.g., reconstruction of a building) and are thus not taken into account in a mid-term analysis.
In order to recognise improvements over the current state we also need to include the current situation of the CI as a defence strategy

- d_0 no change (status quo)

The likelihood of occurrence for the considered attacks are set to $\omega_1 = 0.2$, $\omega_2 = 0.2$ and $\omega_3 = 0.3$ based on reports on contamination (Brown and Darby 1988), earthquakes (Field 2015) and ICS attacks (Kovacs 2016).
We assume that estimates of the expected impact as well as the preparedness level are available either from expert knowledge or simulation. For illustration we work with the data given in Table 1, Table 2 and Table 3 where a 5-tier scale is used such that 1 corresponds to smooth operation and 5 to total failure (intermediate values correspond to limited availability, accordingly).[i] These values are artificial and solely meant to illustrate the approach. Still they should reflect the intuition that more water reservoirs (d_1) increase the preparedness against a contamination (as more pure water is available). More frequent controls (d_2) are assumed to increase preparedness against contamination and a SCADA attack (as it is discovered earlier) and to reduce the expected impact due to a contamination or a SCADA attack (as the spreading gets slower due to the controls). In practice, these values come from interviews with experts in the field that provide estimates of the preparedness and the impact. In case experts may only provide a vague prediction such as the most likely value and an assurance level, a distribution over all possible values can be estimated (König and Rass 2018). Further, simulation methods may support the impact estimation.

Table 1 Estimates for current status d_0

Scenario	Preparedness	Estimated Impact
s_1 contamination	2,3,3,3,4	3,3,4,4,4
s_2 earthquake	3,3,4,4,4	3,3,3,4,4
s_3 SCADA server attack	2,3,3,4,4	3,4,4,4,5

Table 2 Estimates for more water reservoirs d_1

Scenario	Preparedness	Estimated Impact
s_1 contamination	3,3,3,3,4	3,3,3,4,4
s_2 earthquake	3,3,4,4,4	3,3,3,4,4
s_3 SCADA server attack	2,3,3,4,4	3,4,4,4,5

Table 3 Estimates for more frequent controls d_2

Scenario	Preparedness	Estimated Impact
s_1 contamination	3,3,3,3,4	3,3,3,3,4
s_2 earthquake	3,3,4,4,4	3,3,3,4,4
s_3 SCADA server attack	3,3,3,4,4	3,3,4,4,5

These data allow computation of the resilience for each combination of a threat scenario and a defense strategy. Since we have several estimates, we use the R package HyRiM (Rass and König 2018) that is able to optimize distribution-valued payoffs. In order to apply that framework, the maximization of the resilience R needs to be translated into minimization of $-R$ and the resulting values need to be transformed such that the values are positive integers and potential gaps need to be filled by smoothing (see description of the package (Rass and König 2017) for details on how to use it). The resulting payoff matrix is shown in Figure 4.

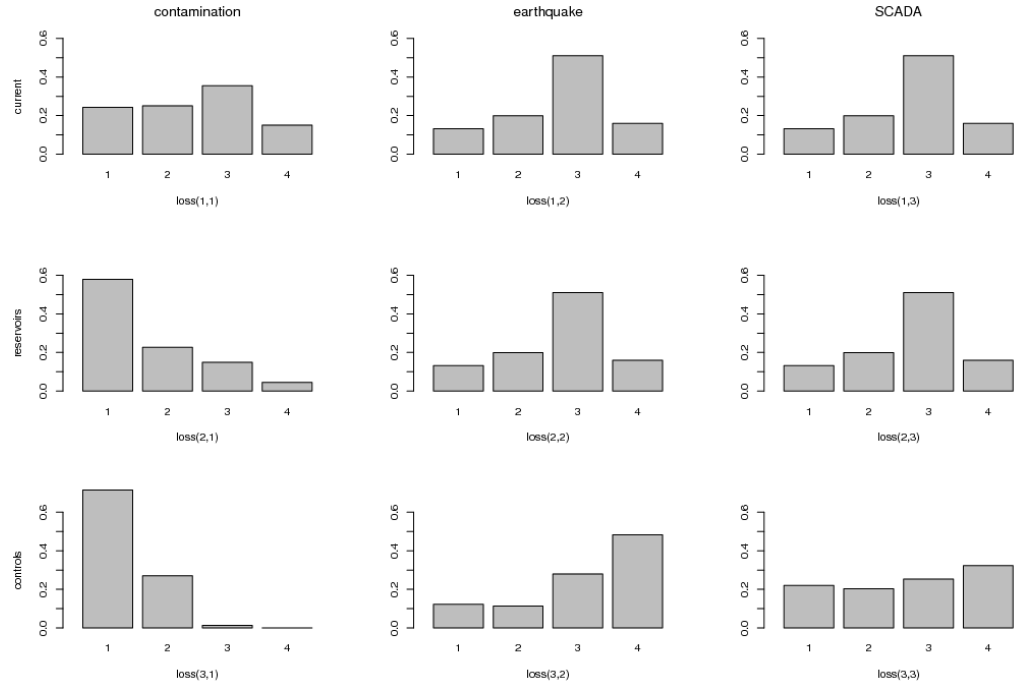


Figure 4 Payoff Matrix

Applying the generalized fictitious play algorithm to solve this game yields the Nash equilibrium (d_0, s_2), that is, the scenario that reduced resilience the most is an earthquake (s_2) and the best way to protect against it is to keep the current state (d_0). In other words, the two defense strategies d_1 and d_2 do not yield to an improvement in this setting and it is necessary to look for other strategies to improve resilience under these threat scenarios. The solution is illustrated in **Figure 5** and reads as follows: from the potential defense strategies, choose "current" $(d_0)$with probability 1 and similarly choose attack strategy "earthquake" (s_2). In case these two strategies are played the resulting distribution of the resilience is shown in the lower right corner.

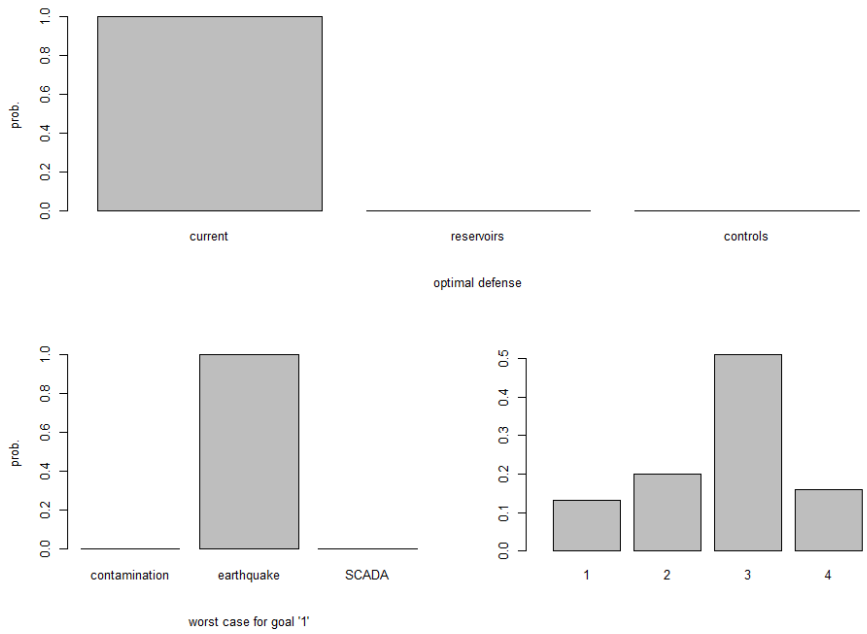


Figure 5 Optimal Strategies and Worst Case Resilience

In a more elaborated example where the list of potential defenses and threats is longer, the optimal solution may not only involve a single defense action but a combination of several actions (a mixed equilibrium). Then, the strategies with a positive likelihood need to be played with relative frequencies that match these likelihoods. For the risk scenarios that constitute the attack strategies this means that several scenarios may occur successively (with relative frequencies corresponding to the likelihoods from the resulting equilibrium). The framework allows optimizing several goals simultaneously which makes it possible to minimize implementation costs of countermeasures at the same time.

CONCLUSION

In the context of critical infrastructures several measures for resilience exist for different domains. Some of these measures allow comparison between different CIs but also for different situations a single CI may face. If it is possible to estimate the resilience for different situations, consequences of protection measures can be compared. Game-theoretic models can be applied to determine the optimal way to protect a system if a list of potential improvements is available. If various threat scenarios are considered it is further possible to determine a worst-case scenario that yields to minimal resilience and estimate the resulting resilience in this case.

While the introduced approach is general in the sense that it is applicable to a wide range of CIs, many issues are still to be investigated in more detail. A big challenge is the estimation of the preparedness level. An estimation of this value depends on many factors such as the weather conditions, so that a single value may not be enough to describe this parameter. Methods for impact estimation as well as the identification of strategies need to be examined in more depth, with different approaches for different sectors. Another issue ignored so far time that plays an important role when talking about resilience. The resilience measure used is time-independent and the game is only played once so that it optimizes the current situation.

ACKNOWLEDGMENT

The author thanks Julian Magin from the Austrian Institute of Technology for interesting discussions.

REFERENCES

Boumphrey, R., and Bruno, M. (2015). “Foresight Review of Resilience Engineering: designing for the expected and unexpected.”

Brown, J. A., and Darby, W. P. (1988). “Predicting the probability of contamination at groundwater based pub-

lic drinking supplies." *Mathematical and Computer Modelling*, 11, 1077–1082.
Cuisong, Y., and Hao, Z. (2008). "Resilience Classification Research of Water Resources System in a Changing Environment." *2008 2nd International Conference on Bioinformatics and Biomedical Engineering*, IEEE, Shanghai, China, 3741–3744.
Field, E. H. (2015). "UCERF3: A new earthquake forecast for California's complex fault system." US Geological Survey.
Ghafir, I., Saleem, J., Hammoudeh, M., Faour, H., Prenosil, V., Jaf, S., Jabbar, S., and Baker, T. (2018). "Security threats to critical infrastructure: the human factor." *The Journal of Supercomputing*, 74(10), 4986–5002.
Gouglidis, A., Shirazi, S. N., Simpson, S., Smith, P., and Hutchison, D. (2016). "A multi-level approach to resilience of critical infrastructures and services." *2016 23rd International Conference on Telecommunications (ICT)*, IEEE, Thessaloniki, Greece, 1–5.
König, S., and Rass, S. (2018). "Investigating Stochastic Dependencies Between Critical Infrastructures." International Journal on Advances in Systems and Measurements, 11(3 & 4), 250–258.
König, S., Schaberreiter, T., Rass, S., and Schauer, S. (2019). "A Measure for Resilience of Critical Infrastructures." *Critical Information Infrastructures Security*, E. Luiijf, I. Žutautaitė, and B. M. Hämmerli, eds., Springer International Publishing, Cham, 57–71.
Kovacs, E. (2016). "IBM Reports Significant Increase in ICS Attacks." *SecurityWeek*.
Martin, H., and Ludek, L. (2013). "The status and importance of robustness in the process of critical infrastructure resilience evaluation." *2013 IEEE International Conference on Technologies for Homeland Security (HST)*, IEEE, Waltham, MA, USA, 589–594.
National Infrastructure Commission. (2017). *Infrastructure and Digital Systems Resilience*. London.
Panteli, M., Mancarella, P., Trakas, D. N., Kyriakides, E., and Hatziargyriou, N. D. (2017). "Metrics and Quantification of Operational and Infrastructure Resilience in Power Systems." *IEEE Transactions on Power Systems*, 32(6), 4732–4742.
Rass, S., and König, S. (2017). "Package 'HyRiM': Multicriteria Risk Management using Zero-Sum Games with vector-valued payoffs that are probability distributions."
Rass, S., and König, S. (2018). "HyRiM: Multicriteria Risk Management using Zero-Sum Games with vector-valued payoffs that are probability distributions." https://cran.r-project.org/package=HyRiM.
Rass, S., König, S., and Schauer, S. (2015). "Uncertainty in Games: Using Probability-Distributions as Payoffs." *Decision and Game Theory for Security: 6th International Conference, GameSec 2015, London, UK, November 4-5, 2015, Proceedings*, M. Khouzani, E. Panaousis, and G. Theodorakopoulos, eds., Springer International Publishing, Cham, 346–357.
Rass, S., König, S., and Schauer, S. (2016). "Decisions with Uncertain Consequences—A Total Ordering on Loss-Distributions." *PLOS ONE*, (S. D. Peddada, ed.), 11(12), e0168583.
Royal Academy of Engineering. (2018). *Cyber safety and resilience - strengthening the digital systems that support the modern economy*. London.
Tokgoz, B. E., and Gheorghe, A. V. (2013). "Resilience quantification and its application to a residential building subject to hurricane winds." *International Journal of Disaster Risk Science*, 4(3), 105–114.
Walker-Roberts, S., Hammoudeh, M., and Dehghantanha, A. (2018). "A Systematic Review of the Availability and Efficacy of Countermeasures to Internal Threats in Healthcare Critical Infrastructure." *IEEE Access*, 6, 25167–25177.
Zimba, A., Wang, Z., and Chen, H. (2018). "Multi-stage crypto ransomware attacks: A new emerging cyber threat to critical infrastructure and industrial control systems." *ICT Express*, 4(1), 14–18.

[i] We chose an odd number of classes to explicitly allow experts to choose a "middle" value to indicate no specific preference to one of the extremes. If this is not desired, a different scale with an even number of classes may be used instead.

Cascading Threats in Critical Infrastructures with Control Systems

Sandra König
Austrian Institute of Technology
Sandra.Koenig@ait.ac.at

Stefan Schauer
Austrian Institute of Technology
Stefan.Schauer@ait.ac.at

ABSTRACT

Critical infrastructures (CIs) increase in complexity due to numerous dependencies on other CIs but also due to the ongoing digitalization in the industry sector. This yields an increased risk of failure of a single CI as the overall systems gets very fragile and sensitive to errors Failure of a single component may affect large parts of an infrastructure due to cascading effects. One way to support functionality of a CI is the use of Industrial Control Systems (ICS) that allow monitoring remote sites and controlling processes. However, this is an additional source for threats as recent cyber-attacks have shown. Further, the additional information for such cyber systems is often not efficiently combined with existing information on the physical infrastructure. We here propose a method to combine these two sources of information in order to estimate the impact of a security incident on CIs, taking into account cascading effects of threats. An implementation of the model allows simulation of the dynamics inside a CI and yields a record of the status of each asset of the CI. The way the assets change their states illustrates the consequences of an incident on the entire CI. Visualization of the results provides an overview on the situation of the entire CI at a certain point of time and a sequence of such visualization over an entire period of time illustrates the changes over time. The results from this analysis may be used to support security officers in analyzing the current (hybrid) state of their CI in case of an incident and thus increase the hybrid situational awareness.

Keywords

Cascading failures, industrial control systems, critical infrastructures, hybrid situational awareness.

INTRODUCTION AND RELATED WORK

Critical infrastructures (CIs) are growing in complexity, not to the least due to the increasing digitalization and stronger interconnections among them. In most of the CIs, Industrial Control Systems (ICSs) are used to allow monitoring physical systems and controlling processes within the infrastructure. Depending on the characteristics of the infrastructure, either Supervisory Control and Data Acquisition (SCADA) systems or Distributed Control Systems (DCSs) are used (Green et al. 2014). Critical infrastructures that span across a large area, e.g., water or electricity provider, typically use SCADA systems which are supervised in a large control center rather than several smaller decentralized centers (as in the case for DCSs). Besides such control systems, CIs typically collect information on their physical domain from video surveillance applications, access control systems, smoke detectors and other sensors. Information on the cyber domain contains data from Intrusion Detection Systems (IDSs), Security Incident and Event Management (SIEM) systems, firewalls or similar systems.

This information on the physical and cyber subsystems within a CI is not always used optimally as it is often treated independently for each of the domains. However, sophisticated attacks such as Advanced Persistent Threats (APTs), as Operation Aurora (Zetter 2010) or Stuxnet (Karnouskos 2011), often start in the cyber system and later spread to the physical system. In this context, an early step of such a sophisticated attack may be the manipulation of data collected by the SCADA system to pretend normal functionality while the actual physical process is interrupted or disrupted. Protecting a CI from these kinds of attacks requires combining information from both the physical and the cyber domain.

Several approaches exist to investigate cascading effects in CI. Petri nets have been applied (and tested) to fluid

critical infrastructures (Ghasemieh et al. 2013). An overview on failure analysis for power systems is given in (Guo et al. 2017). While most of these are domain specific, we aim for a generally applicable high-level model that needs to be refined when applied to a specific area.

More general models on cascading failures in CIs include Markov chain models (Rahnamay-Naeini and Hayat 2016; Wu and Chu 2017). Our choice of finite-state automaton (a.k.a. finite-state machines) rather than Markov chain models is due to their ability to react on external input.

A description of CIs through a network of deterministic finite-state machines is given in (Klemetti et al. 2016), who applied the model to an electric grid as well as mobile networks. The increasing uncertainty about sates over time is captured by associating a probability distribution to each automaton rather than using a probabilistic automaton.

In this paper, we propose a hybrid view that combines information from the physical and the cyber domain to support the analysis of cascading effects of an incident on the entire CI. The proposed automaton model represents the functionality of a CI's assets through different states and analyses how these states change due to the incident. The implementation of the model represents the network of interdependent physical and cyber assets as a graph and simulates the dynamics within the critical infrastructure using stochastic processes. We introduce the methodology with a focus on critical infrastructures that apply ICS to monitor their processes as an example of a cyber-physical system.

The paper is structured as follows. A hybrid situational awareness model is introduced that combines and extends existing cyber and physical situational awareness to obtain a holistic view on the CI. Further, a model for characterizing the cascading effects of an incident in the CI is described and its use for impact estimation is sketched. The approach is illustrated with a small example and the article finishes with concluding remarks.

HYBRID SITUATIONAL AWARENESS

The current state of the cyber and physical domain is conveniently described by a *cyber situational awareness (CSA)* and a *physical situational awareness (PSA)* system, respectively. The term situational awareness is generally understood as a complete description of the environment including information on potential threats. To this end, it combines several existing sources, e.g., it incorporates information from cameras or access control systems for the physical domain or technical vulnerability databases for the cyber domain. Both CSA and PSA report events that happen in the corresponding system and issue an alarm if such an event threatens the system. A cyber alarm may be a detected virus in the system (say, a malware) while a physical alarm may be a fire in a building that is part of the CI. Further, both CSA and PSA observe numerous events that do not threaten the system directly because they are legitimate activities or do not have a high criticality.

When the information from the CSA and PSA are combined, they build up a *hybrid situational awareness (HSA)* that not only contains information from both subsystems but also combines the two sources of information to obtain new insights about the current status of the CI (Schauer et al. 2019). To achieve that, the HSA links events and alarms from the cyber and physical domain and is able to identify combinations of those events that may indicate a threat to the CI. Furthermore, it also shows which cascading effects might occur within the entire infrastructure due to such an (cyber, physical or hybrid) alarm by providing a list of assets which might be affected by the incident. For example, consider the following two events: an employee leaves the area of the CI in the evening, which is monitored by the access control system at the main gate; second, his credentials are (correctly) used to log in to a computer somewhere inside the CI, which is monitored by a host-based IDS. Both events individually are not of special interest, since they are legitimate in the physical and the cyber domain, respectively, and will not trigger an alarm in the CSA or PSA. However, the combination of both events within a short period of time indicates that there might be a problem, since the same employee cannot be at two places at (roughly) the same time. Such combinations can be caught by the hybrid view of the HSA and are therefore called *hybrid threats* or *hybrid alarms* as they threaten the system but only show up in the hybrid view.

The identification of such hybrid alarms is often difficult as it depends on the context if a combination of two events represents a threat to the infrastructure or not. Therefore, such an identification can be achieved using a rule based system which either defines a set of valid (i.e., a whitelist) or invalid (i.e., a blacklist) combinations of events. However, such an automated detection of correlations between cyber and physical events may only yield candidates for hybrid alarms but expert knowledge is required to decide if this is indeed an alarm or not.

In short, the benefits of a HSA as described here include the following:

- Awareness is increased and operators gain an overview on their cyber-physical system
- Implicit and potentially unknown interdependencies become clear
- Decision making for port operators is facilitated when information about incidents can be estimated and compared

One way to identify hybrid alarms is the correlation engine introduced in (Schauer et al. 2019). The potential cascading effects on the entire CI is analyzed based on a graphical representation of the CIs assets and a stochastic model that describes the propagation through this graph. In the following section, the threat propagation engine is described in more detail.

HYBRID THREAT PROPAGATION

A formal description of a CI is often based on a graph representation where the nodes correspond to single assets of the CI (e.g., a server) and edges to dependencies between them. Our approach is also graph based and additionally, nodes are classified as either cyber or physical, depending on the system they belong to. Directed edges between two assets indicate that one depends on the other. These dependencies include the ones among the cyber and physical assets, respectively, but also interconnections between the two domains. Particularly these interconnections are often not explicitly given. Hence, when building up this asset graph, it is important to discuss with experts who are familiar with the different parts of the CI, i.e., the physical and the cyber assets, to obtain a comprehensive and in-depth description of the entire system. For example, when examining the situation of a water provider it is necessary to talk to employees who know the water distribution network and with others familiar with the SCADA system.

The graph representation is further extended such that each node (i.e., each asset) can be in one of several different states. The state of an asset changes either due to an external incident or due to a change state of an asset it depends on. In both cases, this state change is triggered from outside and does not necessarily happen in constant time intervals. Thus, we describe the dynamic of a single asset by a finite-state automaton (Paz and Rheinboldt 2014) rather than a Markov chain where changes happen at predefined points in time. The dependencies between two assets are manifold and complex as they depend on many factors such as the state of all assets they depend on (directly or indirectly) as well as external influences (such as weather). In order to capture these phenomena, we choose a probabilistic automaton that predicts the next state through a probability distribution over the set of all possible outcomes rather than a precise prediction.

Cascading effects usually have a trigger starting the process. In our case, such a trigger is an incident that causes an alarm reported by CSA, PSA or HSA that is correspondingly called cyber, physical or hybrid alarm (in the following, we will consider these alarms as a start of the cascading while keeping in mind that these are triggered by an incident or an unusual combination of events). In our approach, an alarm has attributes such as name or criticality to describe its nature. Depending on its type, an alarm may influence the dependencies between two assets (e.g., two neighboring rooms are strongly dependent in case of a fire alarm but to a lower degree in case of burglary). In order to capture this dynamic, we choose to model assets as probabilistic Mealy automaton (Paz and Rheinboldt 2014; Rabin 1963) as these also provide output after each state change. More explicitly, the inner structure of an asset looks as displayed in Figure 1.

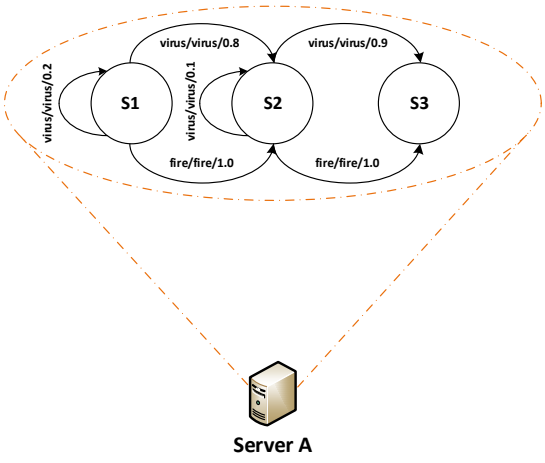


Figure 1. Representation of an asset as a probabilistic Mealy automaton

The asset can be in one of finitely many states (e.g., states s_1, s_2, s_3 as in Figure 1) and changes its state with a certain probability. This state change is due to an input and yields an output as a response to the state change. This is indicated by adding a triple of the form input/output/probability to the edges that describe potential state changes. For a Mealy automaton the output does not only depend on the current state of the asset but also on the input. This allows to forward information on an alarm from one asset to other assets depending on it. A more formal description of this model is given in (König et al. 2019), we here focus on its applicability to the security of CIs.

Dynamics inside a CI

Once the behavior of a single asset is modeled, the dynamics inside a CI can be described when the dependencies between the assets are known. Identification and modeling of dependencies inside a CI are challenging but a necessary part of risk assessment process (Schaberreiter et al. 2013). In our setting, dependencies between assets depend on static factors such as the type of an asset but also on dynamic factors such as the current state of the asset that affects the other one or the type of alarm. As an example, consider a building that is affected by a fire. The room where the fire breaks out may "inform" its neighboring rooms about the fire (i.e., the alarm) as well as how much it is affected by it (i.e., its current state). Both pieces of information influence the state change of the neighboring rooms. The effect on the entire CI due to a fire may be smaller (given that fire safety regulations are working) than, for example, in case of electricity outage where typically an entire floor, the whole building or the entire CI is affected. However, the degree of damage for a specific room also depends on the state of assets it depends on, e.g., if a small fire only affects a PC it is less likely to affect neighboring rooms than if the entire room is on fire.

Using probabilistic automaton to describe the behavior of the assets, the dynamics inside the CI become stochastic as well. This fits into the current line of research where complex systems are described through stochastic processes (König and Rass 2018; Rahnamay-Naeini and Hayat 2016; Wang et al. 2012). Such models are able to take into account the unpredictability of systems where an exact description is hardly possible due to the high complexity as well as due to unknown or non-deterministic factors. Still they provide a formal description of the system that allows an analysis of the average behavior of the system.

Implementing this stochastic model yields empirical data on the behavior of the assets that allows prediction about the future development of the CI. If enough information on the CI is available, e.g., for a specific sector such as smart grids, simulation approaches may be used as an alternative to a formal mathematical description of the dynamics (Findrik et al. 2016; Jaromin et al. 2013; Song et al. 2016). If available, testbeds may be used to simulate different scenarios (Green et al. 2016) and gain some additional insight in the dynamics of a system.

Overall State of a CI

The condition of a CI can be described through the level of functionality of its components. Clearly, if all components were in a bad state, the CI will not be able to provide the expected output while everything works fine if all components were in a good state. However, things are less clear in situations where some assets are not fully operating: Is the CI still able to provide the desired output if some components fail or only work to a certain degree? In order to answer this question, we choose a set of possible states, say "properly working", "limited functionality", and "failure" and let each asset of the CI be in exactly one of these states. For a formal analysis the states may be represented by numeric values, say 1 (properly working), 2 (limited functionality), and 3 (failure). A visualization of the states of all assets provides a basic overview on the overall state of the CI, e.g., assets colored in green (state 1), orange (state 2) and red (state 3), demonstrates where a problem affects the CI the most. The overall state of the CI may be measured by counting the number of assets in the worst state. However, not all assets are of the same importance to the CI operator, so one may only care about the output of the CI, e.g., measure the quality or quantity of the provided water.

IMPACT ESTIMATION FOR CASCADING THREATS

Based on the threat propagation model described above, it is possible to simulate the behavior of all assets of the CI (in the physical as well as in the cyber domain) after an incident. The state changes of the assets indicate the development of a threat and highlight its cascading behavior over different subsystems. The spreading process is reproduced by defining a set of states and transmission probabilities such that the probabilistic Mealy automatons simulate the behavior over time. Recording the state changes of all assets over time (yielding a time series for each asset) indicates how the spreading evolves as the states represent how strong assets are affected.. Depending on the considered scenario, it may be necessary to distinguish several alarms coming in (e.g., from different assets) which can be solved by a prioritization in terms of criticality or time. A basic implementation

can be done in a software such as MATLAB where the prioritization of alarms can be implemented as a FIFO (First In, First Out) queue.

Mimicking the cascading of threats based on the described model requires a comprehensive description of the CI. This particularly includes a list of all the relevant assets within the cyber and physical system including their interdependencies as well as the connections between these two systems. Then, the set of states of each asset needs to be defined as well as the words used for communication between the assets (i.e., the input and output alphabets of the Mealy automatons) that describe the considered alarms. This information may be collected in discussion with (risk) managers who typically have a good overview on the entire system.

After the general specification of the CI, more situation specific aspects need to be taken into account. For each pair of states, the state transitions function and output function need to be formalized. The output function assigns a deterministic output to every pair of input and state which corresponds to the message sent to the dependent asset. In the probabilistic setting, the transition function assigns a probability distribution over all possible states to each combination of an input and a state. The next state is then chosen according to this probability distribution. This more detailed information is collected in discussions with domain experts as knowledge of the processes is required to estimate transmission likelihoods or to predict the most likely next state. Asking for exact estimates of probabilities may be avoided by rather asking for the most likely value combined with an assurance and estimate a probability distribution from these inputs (König and Rass 2018).

With this general and specific information, it is possible to simulate the consequences of an alarm affecting one or more assets by implementing the random behavior of the assets. Recording the state changes over time provides empirical data that can be analyzed statistically. First, it is possible to predict the overall state of the CI by estimating how many assets fail on average (i.e., are in the worst state). Second, one can look at single assets and estimate the likelihood that it is affected or fails. This may be interesting for core assets that should be particularly protected but also provides an overview on state of the CI. To this end, the graphical representation of the infrastructure is extended such that each node is assigned a color depending on its average state, e.g., green if the likelihood of failure is low and red if it is high.

In case the analysis of the current situation has indicated problems (e.g., an important asset is likely to fail, or several assets are likely to end in a state of reduced operation), additional simulations allow testing potential countermeasures. For example, if a sensitive asset is likely to fail, the simulation may be rerun with an increased protection of the asset or a second asset in place which is organized as a backup. Moreover, if a simulation indicates that a large part of a CI is likely to be affected by an alarm additional preventive measures on an organizational level may be required to reduce the expected damage. In this sense, the proposed threat propagation method is not only a tool to analyze the impact of cascading effects on a CI but may also be used to investigate various methods to reduce the expected damage. In general, the security officers monitoring the physical and the cyber domain within a CI (e.g., within a port) will instantiate the model. Hence, it is understood as a collaborative approach with data coming from experts in their respective fields; however, the collaboration is realized in physical meetings and discussions rather than in an online tool.

EXAMPLE

Consider a water provider whose main aim is availability of water with a focus on the quality of drinking water. To reach this goal, a SCADA system is applied to ensure water production, purification and distribution. In this example, the physical domain contains assets such as pumps, wells, water plants and the water distribution system equipped with sensors and Programmable Logic Controller (PLCs). Further, the cyber domain contains assets such as laptops that allow remotely controlling pumps, the SCADA server, the communication system (including switches) and other systems. An extract of this system is displayed in Figure 2. Each component is descried through a Mealy automaton (as shown in Figure 1) but we hide the detailed description to focus on the dependencies between components.

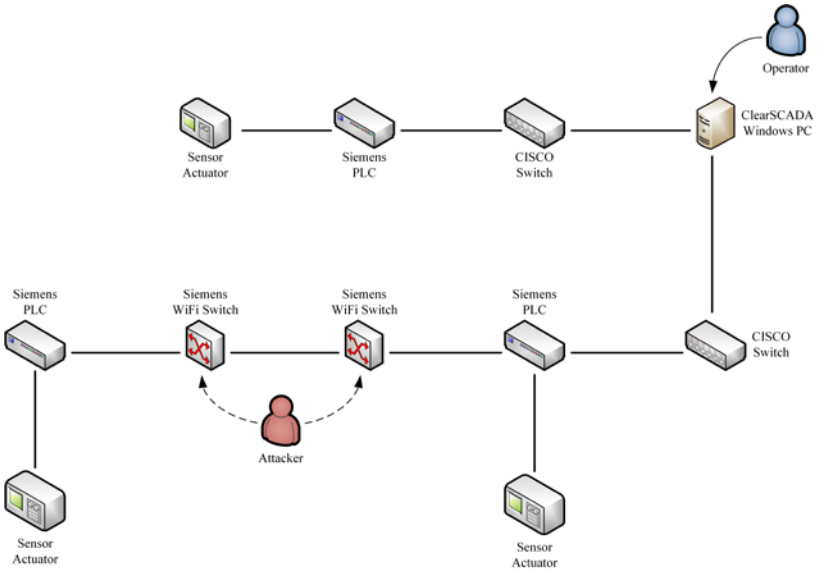


Figure 2. High-level representation of a part of a water provider (automaton details hidden)

An APT (Advanced Persistent Threat) attack on this system, as described in (Gouglidis et al. 2018), typically consist of several steps involving both the cyber and the physical system. Prior to the actual attack, information on the company is collected for a targeted attack, e.g., by social engineering. Then, a device from the cyber network connected to the WiFi network is compromised. This allows launching an attack that causes failure of some controllers (physical assets) and might further give access to the internal company network (cyber asset). Having access to a management server enables the attacker to modify controller logic to cause failure of controllers or switches in the physical network. Depending on the importance of the manipulated devices, this may cause significant damage to the CI operator.

Analyzing cascading effects in this network with our approach involves the following steps:

- Identify all important assets (physical and cyber) and specify the corresponding probabilistic automatons. In particular, define the set of potential states, the transition regimes and the notification behavior (the output function) for each asset.
- Identify all dependencies between the assets both inside the corresponding domains as well as between domains
- Identify all possible alerts (physical, cyber and hybrid) that may cause cascading effects

For the considered attack, the first two steps yield the graph model of the CI as shown in Figure 2 (the graphical representation quickly gets complex so that only a subnetwork of the CI is depicted). For each alert it is now possible to simulate the effects on the entire CI and represent the resulting states of the assets graphically.

A popular goal of such an attack is the SCADA server that allows the manipulation of switches and thus enabling denial-of-service attacks (DoS). Alternatively, technical vulnerabilities of logically connected devices such as sensors or cameras may be exploited to change their behavior or modify data such that wrong measurements or surveillance data are reported. For illustration purpose we consider an attacker who gains access to two switches through the WiFi. This may affect connected devices such as PLCs (Programmable Logic Controllers) which in turn may compromise other dependent devices. The propagation is illustrated in Figure 3 where affected devices are marked red.

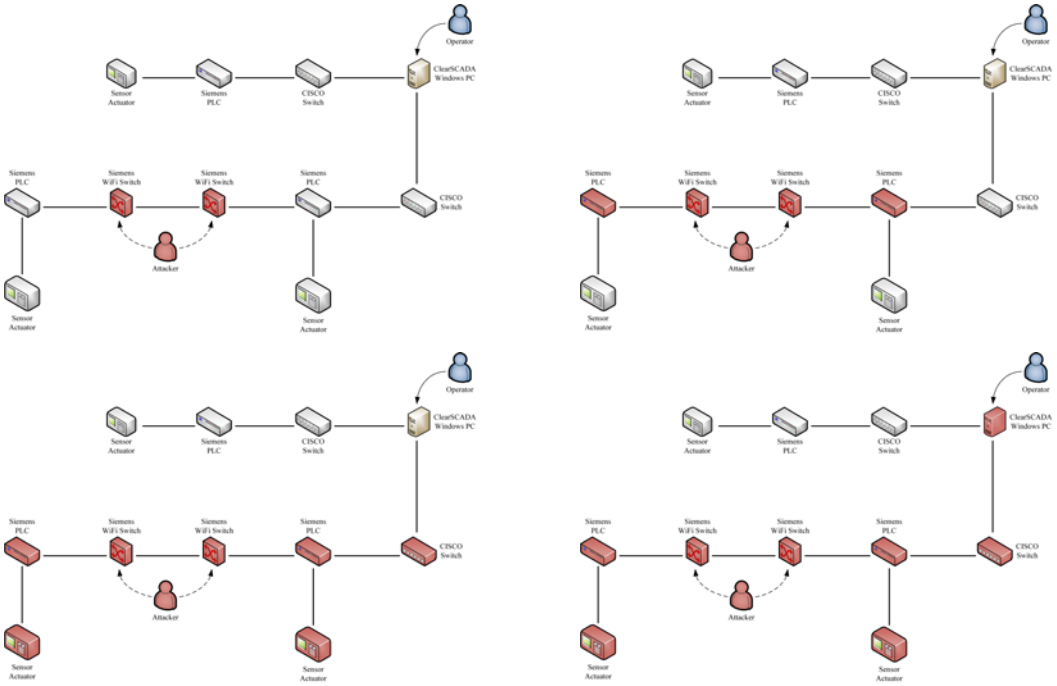


Figure 6. Cascading effects of an attack on two switches of a water provider

CONCLUSION

Investigating cascading effects of an incident within a CI requires the combination of available information on both the physical domain and a cyber domain (including control systems such as a SCADA system). A formal analysis of the CI based on a graph model where nodes are represented as probabilistic Mealy automatons allows investigating the behavior after an incident that occurs in the CI. This model considers different levels of functionality of each component while taking into account the unpredictability of complex systems. Since it combines information from CSA and PSA, the approach presented here yields a hybrid view on the infrastructure and is able to identify threats that are not recognized if the two domains are treated as independent. Simulations based on this model allow estimating the level of functionality of each component within the entire system. This provides an overview on the state of the considered CI after an incident, taking into account cascading effects.

The model described in this paper aims to find a balance between a detailed description of the CIs assets and interdependences and feasibility of implementation. The current description is limited in terms of the source of information used. Extensions may take into account social components (addressing the well-known statement that humans are the weakest link in a security chain) or more technical details. Future directions of research may also focus on the identification of hybrid threats and ways to estimate the impact for a specific type of CIs in more detail.

ACKNOWLEDGMENT

This work was supported by the European Commission's project SAURON (Scalable multidimensional situation awareness solution for protecting European ports) under the Horizon 2020 framework (Grant No. 740477).

REFERENCES

Findrik, M., Smith, P., Kazmi, J. H., Faschang, M., and Kupzog, F. (2016). "Towards secure and resilient networked power distribution grids: Process and tool adoption." *2016 IEEE International Conference on Smart Grid Communications (SmartGridComm)*, IEEE, Sydney, Australia, 435–440.

Ghasemieh, H., Remke, A., and Haverkort, B. R. (2013). "Survivability Evaluation of Fluid Critical Infrastructures Using Hybrid Petri Nets." *2013 IEEE 19th Pacific Rim International Symposium on Dependable Computing*, IEEE, Vancouver, BC, Canada, 152–161.

Gouglidis, A., König, S., Green, B., Rossegger, K., and Hutchison, D. (2018). "Protecting Water Utility Networks from Advanced Persistent Threats: A Case Study." *Game Theory for Security and Risk*

Management, S. Rass and S. Schauer, eds., Springer International Publishing, Cham, 313–333.
Green, B., Frey, S., Rashid, A., and Hutchison, D. (2016). "Testbed diversity as a fundamental principle for effective ICS security research." London.
Green, B., Paske, B., Hutchison, D., and Prince, D. (2014). "Design and construction of an Industrial Control System testbed."
Guo, H., Zheng, C., Iu, H. H.-C., and Fernando, T. (2017). "A critical review of cascading failure analysis and modeling of power system." *Renewable and Sustainable Energy Reviews*, 80, 9–22.
Jaromin, R., Mullins, B., Butts, J., and Lopez, J. (2013). "Design and Implementation of Industrial Control System Emulators." *Critical Infrastructure Protection VII*, J. Butts and S. Shenoi, eds., Springer Berlin Heidelberg, Berlin, Heidelberg, 35–46.
Karnouskos, S. (2011). "Stuxnet worm impact on industrial cyber-physical system security." IEEE, 4490–4494.
Klemetti, M., Puuska, S., and Vankka, J. (2016). "Entropy as a metric in critical infrastructure situational awareness." E. M. Carapezza, ed., Baltimore, Maryland, United States, 98250K.
König, S., and Rass, S. (2018). "Investigating Stochastic Dependencies Between Critical Infrastructures." International Journal on Advances in Systems and Measurements, 11(3 & 4), 250–258.
König, S., Rass, S., Rainer, B., and Schauer, S. (2019). "Hybrid Dependencies between Cyber and Physical Systems." *accepted for publication*, London.
Paz, A., and Rheinboldt, W. (2014). *Introduction to Probabilistic Automata*. Elsevier Science, Burlington.
Rabin, M. O. (1963). "Probabilistic automata." *Information and Control*, 6(3), 230–245.
Rahnamay-Naeini, M., and Hayat, M. M. (2016). "Cascading Failures in Interdependent Infrastructures: An Interdependent Markov-Chain Approach." *IEEE Transactions on Smart Grid*, 7(4), 1997–2006.
Schaberreiter, T., Kittilä, K., Halunen, K., Röning, J., and Khadraoui, D. (2013). "Risk Assessment in Critical Infrastructure Security Modelling Based on Dependency Analysis." *Critical Information Infrastructure Security. CRITIS 2011.*, Lecture notes in computer science, Springer, Berlin.
Schauer, S., Rainer, B., Museux, N., Faure, D., Hingant, J., Rodrigo, F. J. C., Beyer, S., Peris, R. C., and Lopez, S. Z. (2019). "Conceptual Framework for Hybrid Situational Awareness in Critical Port Infrastructures." *Critical Information Infrastructures Security*, E. Luiijf, I. Žutautaitė, and B. M. Hämmerli, eds., Springer International Publishing, Cham, 191–203.
Song, J., Cotilla-Sanchez, E., Ghanavati, G., and Hines, P. D. H. (2016). "Dynamic Modeling of Cascading Failure in Power Systems." *IEEE Transactions on Power Systems*, 31(3), 2085–2095.
Wang, Z., Scaglione, A., and Thomas, R. J. (2012). "A Markov-Transition Model for Cascading Failures in Power Grids." *2012 45th Hawaii International Conference on System Sciences*, IEEE, Maui, HI, USA, 2115–2124.
Wu, S.-J., and Chu, M. T. (2017). "Markov chains with memory, tensor formulation, and the dynamics of power iteration." *Applied Mathematics and Computation*, 303, 226–239.
Zetter, K. (2010). "Google Hack Attack Was Ultra Sophisticated, New Details Show." *WIRED*.

On the usage of Virtual Reality for Crisis Management exercises in Critical Industrial Sites

Aurélie CONGÈS
IMT Mines Albi
aurelie.conges@mines-albi.fr

Frédérick BÉNABEN
IMT Mines Albi
frederick.benaben@mines-albi.fr

Olivier PIERRE
Immersive Factory
opierre@immersivefactory.com

Francis SAVIC
Report One
fsavic@report-one.com

Olivier CHABIRON
Immersive Factory
ochabiron@immersivefactory.com

Matthieu LAURAS
IMT Mines Albi
matthieu.lauras@mines-albi.fr

ABSTRACT

EGCERSIS is a starting research program aiming at defining a virtual collaborative training space for crisis management. It should provide the users (first and second aid, firefighters, etc.) with a way to virtually perform operational and strategic tasks of crisis management in digital twins of critical infrastructures. The training system is structured according to four main components: (i) protocol and tools for digital twins generation, (ii) scenario editor dedicated to defining crisis use-cases within the modeled digital twins, (iii) integration with the technological crisis management platform (RIO-Suite), and (iv) monitoring component in charge of the continuous edition of dashboards (real-time and afterward). The main expected benefit of the EGCERSIS program is to create a breakthrough in the way training and exercises are performed in critical sites.

Keywords

Virtual Reality, Training, Coordination.

INTRODUCTION

Critical sites are of various types. In this article, it is considered that the word “critical” refers to the impact of a failure of a considered *system* on the capacity of the whole human *territory* to keep on performing its missions (e.g. first necessity supplying, protection, energy providing, water, health care system, etc.) as stated by some measure of performance (Stewart, 1992). The *territory* is a geographical space that covers the spatial extension of a government’s jurisdiction (Gottmann 1975). The *system* concerns a critical site that is located in the considered territory. For instance, the system may refer to a power station, a production system, a supply chain, a transport infrastructure, or a health care system (Yodo and Wang 2016).

These critical sites are legally obliged to perform training exercises to prepare for any crisis situation within the infrastructure itself. These exercises can be set up twice a year, once a year, every two years, or more or less frequently depending on the criticality of the considered system and the legislation of the considered territory.

However, setting up such an exercise is quite a complicated task, enacting the planned exercise is a difficult task too, and exploiting the results of the exercise in a productive manner is complicated as well. All these elements make crisis exercise a time and resource-consuming task with low benefits. It is a regulatory, mandatory and necessary activity which is nowadays neither effective nor efficient. The EGCERSIS research program believes that the use of virtual reality (VR) may break the barriers and reduce almost all drawbacks mentioned. This

might be a huge and significant giant leap forward in the domain of preparation (on an efficiency point of view and even on a legal point of view).

This article is structured according to the following sections: first, an overview of the context, expectations and related work is presented. Then the functional architecture of the whole virtual training system is described. Finally, the next steps are listed with perspectives as well.

CONTEXT OF THE EGCERSIS RESEARCH PROGRAM

This section aims at defining the main objectives of the EGCERSIS program. One key challenge is to identify the pros and cons of the EGCERSIS approach (based on VR) compared to the use of classical real size exercises.

The location of the EGCERSIS research program

The very classical vision of crisis management includes the following phases: *prevention*, *preparation*, *response* and *recovery* (Atlay and Green, 2016) as shown in Figure 1. The preparation phase is one critical phase for the efficiency and the effectiveness of crisis management (and especially for the efficiency and effectiveness of the response phase). If the prevention phase aims at trying to avoid the use of the response phase (by preventing the occurrence of the critical events), the prevention phase aims at supporting the response and making it as efficient and effective as possible (by setting up all the necessary resources and processes basically).

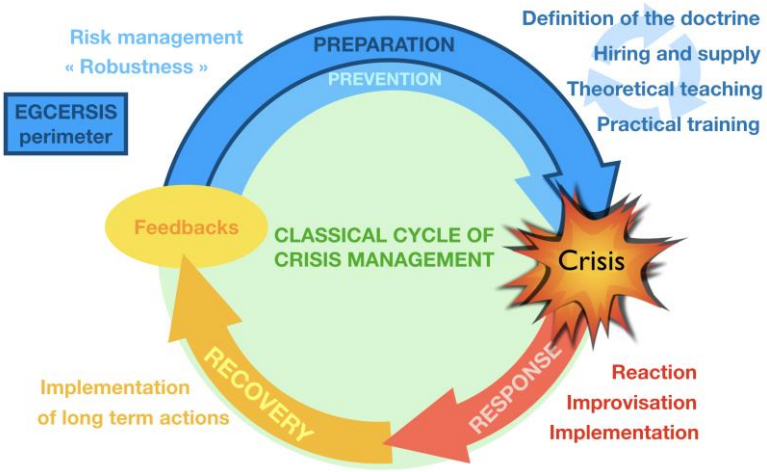


Figure 1: The location of the EGCERSIS research program in the classical cycle of crisis management

During the preparation phase, specifically in the case of critical industrial sites, there are several tasks that must be performed (**Erreur ! Source du renvoi introuvable.**). First, the doctrine must first be defined. On a practical point of view, this step concerns the definition of internal and external action plans. Then, the question of resources (human and equipment) must be considered in terms of availability and appropriateness, which concern hiring and supply. Thirdly, there is a step of theoretical training, before the fourth step of practical training. The theoretical training is more about "know" while practical training is more about "know how". In the preparation phase, the EGCERSIS program focuses on the practical training step, including exercise definition, enactment, and improvement.

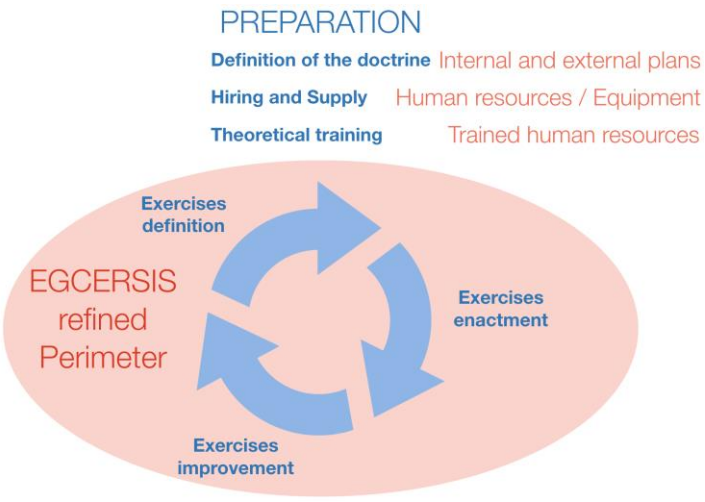


Figure 2: The refined location of the EGCERSIS research program in the Preparation phase for critical sites

The reason why the EGCERSIS research program focuses on those steps (definition, enactment, and improvement of exercises) of the Preparation phase is mainly due to the fact that these steps are the less efficient ones. This part of the preparation truly requires a concrete breakthrough to overcome the current limitation training exercises.

The limitations of training exercises

In Europe, the SEVESO[1] industrial sites are required to conform to a set of measures related to their risks. Usually, it implies to define internal plans (describing the organizational measures set up to deal with *alert*, *evacuation*, *treatment* ...) and external plans, if necessary (similar to the internal plans but dedicated to the wider impacted perimeter of the site). Besides, it is usually mandatory to run exercises dedicated to implement the internal and/or external plans and to practice the activities of first aid actors (in contact with the event), second aid (people on site trained to intervene on the event) and institutional responders (e.g. firefighters).

However, these exercises have generally a lot of drawbacks. Basically (Ardila, *et al.* 2013) summarizes the main issues: "(i) traditional training simulated-based systems are expensive and offer little flexibility (e.g. it is not possible to simply burn up a building every time a drill is carried out); (ii) real training in the field of emergency management is very expensive and complicated regarding the harmonization of procedures between agencies". More precisely, the following identifies specific drawbacks in the context of the program.

During the preparation of the EGCERSIS research program, interviews have been made of five local safety and security directors of critical industrial sites about the efficiency and effectiveness of real-size crisis management exercises in their organizations. Though there are obvious benefits and these exercises are mandatory on a legal point of view, the interviewed professional described jointly the same kind of limitations and drawbacks of the current way of managing the preparation phase of these critical sites mainly with real-size exercises. Basically, their vision can be discomposed according to the two dimensions presented in Table 1: columns represent the lifecycle of an exercise (*definition*, *enactment*, and *improvement*) while lines represents the expectations of an exercise, *i.e.* the need for participants to learn appropriate reactions and processes (*short term impact*), to remember these reactions and processes (*long term impact*), to be as many as possible to benefit from the exercise (*inclusiveness*), to be trained by the exercise on a various range of scenario (*coverage*).

Table 1. The limitations of real size exercises in critical sites

	Definition	Enactment	Improvement
Short term impact **Does the system learn something beneficial?**	• The light manpower that can be dedicated to the definition of the crisis scenario.	• The poor realism of the exercise due to the lack of special effects and real damages.	• The lack of concretely exploitable, significant, and capitalizable data except for some pictures and movies

[1] The **Seveso directive** is the generic name of a series of European directives ruling the management of industrial sites that present major accident risks (so called SEVESO sites).

	• The lack of support equipment (only maps and plans) to create relevant exercises.		(in the best case).
Long term impact **Will the system remember what has been learned?**	• The difficulty to plan an exercise with the objective of making it a long term benefit, considering that this objective may seem secondary with regards to short term impact and relevance of the scenario.	• The low frequency of these exercises due to the actual disturbing impact on the site.	• The difficulty to mobilize the workforce after the exercise considering their impression of loss of time. • The lack of concretely exploitable, significant, and capitalizable data except for some pictures and movies (in the best case).
Inclusiveness **Are all the people that should be included, actually included?**	• The difficulty to expect a large "official" mobilization of the workforce considering the actual disturbing impact of such an exercise on the site.	• The practical difficulty to explain the scenario to a lot of people and to have them commit all together in it. • The low involvement of people due to the weak sensory impact of a simulated exercise on themselves.	• The difficulty to set up a transversal feedback process to generate "lessons learned" and "significant benefits" on as much as possible sectors of the organization.
Coverage **Are all the scenarios that should be studied, actually studied?**	• The hard limits for the scenario that can be designed due to the fake aspect. • The complexity of including as many dimensions as possible in a one-shot realistic scenario.	• The low frequency of these exercises due to the actual disturbing impact on the site. • The complexity of running "live" a scenario that would include as many features as possible.	• The complexity of a fruitful analysis of the exercise with regards to all the relevant dimensions that should actually be considered.

In a nutshell: (i) mobilizing concerned actors is difficult, (ii) designing realist and fruitful scenarios is difficult to obtain, (iii) completeness, or at least a covering variety of scenarios is difficult to get, principally because of the low frequency of such exercises, (iv) implication of human beings, and the impact on them is deeply varying, and even unpredictable (Dolidon, 2018).

Related works on the use of Virtual Reality with regards to classical real size exercises

The use of Virtual Reality in crisis management has been studied a lot in the last twenty years, from its appearance to its current maturity. Basically, previous related research works have identified the pros and cons of the usage of VR:

- Identified advantage: Most authors mention the benefit of VR on a realistic point of view: "*Virtual reality is a powerful technology for creating a sense of immersion and 'intelligent' virtual characters have recently been integrated into virtual worlds for the purpose of training*" or "*the virtual environment will allow trainees users to gather all the necessary visual and auditory contextual information to make the necessary decisions*" (Dugdale, et al. 2004). The flexibility is also another positive point mentioned: "*Virtual Simulation's greatest advantage over traditional planning processes is that there is no pre-established model or hard-coded rules to follow.*" (Hendela, et al. 2006) or "*Virtual Simulation provides flexibility and ease of preparation while stimulating creative and critical thinking.*" (Hendela, et al. 2006) or "*Replicability; scalability and adaptability, testing of new technologies*" (Berndt, et al. 2018). The last main point concerns the price: "*The use of 3D virtual environments for conducting training exercises can provide numerous advantages such as flexibility, relative low cost given a midterm horizon and large scenario development capabilities.*" (Zarraonandia et al. 2014) or "*a network-based system that integrates reality and simulation will be, on the one hand, relatively cheap because all expenses that real in-site training entails (such as moving many people, vehicles) are reduced and, on the other, will facilitate the interoperability and harmonization of procedures between agencies.*" (Ardilla, et al. 2013). Finally, some authors also mention the safety aspect of using VR: "*In contrast with exercises on site, there is little if any danger to the paramedics in a VR simulation. Mistakes can be made without adverse consequences, allowing for experimentation and learning by experience. Because of safety requirements on site, some risks can be presented in an even more realistic way in VR simulations (e.g., fire, explosions, toxic gas).*" (Berndt, et al. 2018)

- Identified disadvantages: One major point concerns the lack of interactions: "*Although many virtual environments strive to offer realism in their simulations of weather, population, and incident happenings, they often fall short in terms of collaboration among simulation participants: unless participants are at the same physical location, their ability to see and interact with one and other is limited.*" (Wright, et al. 2008), or "*interactivity that is possible may not be truly synchronous*" (Wright, et al. 2008) or "*such systems […] use simplistic models of cognitive behavior and emotion to simulate intelligence, and usually only allow one user at a time to participate in the training scenario.*" (Dugdale, et al. 2004). Even if the two articles are quite old, the multi-player aspect is still an issue for deep interaction. Another point concerns the difficulty to implement such systems: "*However, the adoption of 3D virtual environments, in practice is not as widespread as might be expected due to the difficulties associated with their design and development.*" (Zarraonandia et al. 2014) or "*such systems typically require huge computational resources*" (Dugdale, et al. 2004). Finally, they are also some drawbacks regarding the completeness of the sensations "*it does not allow users to obtain the necessary tactile information (e.g. physical contact was used between trainees to reinforce a verbal message or to initiate an action)*" (Dugdale, et al. 2004) or simply the question of virtual reality sickness "*lack of the same physiological stimulation, the longstanding problem of possible simulator sickness and the lack of tactile feedback and "hands-on" experience of real-life exercises*" (Berndt, et al. 2018).

Finally, the conclusion that can be suggested, based on the previous elements, is that VR presents a lot of significant advantages (especially compared to classical exercises). Besides, most of the identified disadvantages are due to its newness. Both these statements make it a very good candidate for a tangible and meaningful innovation: a lot of good points that may contribute to a breakthrough and several bad points that should be corrected with the technological improvements.

The objectives of the EGCERSIS research program

From the two previous subsections regarding limitations of real size exercises and benefits of Virtual Reality, the EGCERSIS research program has been defined according to the following main objective: providing security managers with a framework dedicated to preparation and training for crisis management on critical industrial sites. The idea is to cross virtual reality and decision support in an uncertain environment. The virtual training environment should provide two main features:

- An immersive experience in the digital twin of the critical industrial site in order to experiment with the predefined scenario and prepare intervention teams (first aid, second aid, external responders, etc.). This will result in the creation of a twin of the site in VR, where the participants will be able to evolve thanks to VR goggles, and where they will be confronted to the predefined crisis scenario.
- Monitoring and supervision tools to support the virtual exercises and to generate useful and actionable real time and later reports to understand and capitalize on the played exercises.

These two main features will be implemented through four main components:

1. The exercise editor (dedicated to site modeling and scenario definition)
2. The virtual environment (dedicated to multi-player scenario enactment).
3. Decision support tools (dedicated to accompanying decision makers of the crisis cell).
4. Dashboard tools (dedicated to *in situ* and *a posteriori* analysis of players, exercise and plans).

These components and the provided features should tackle the limitations previously identified in Table 1, as shown in **Erreur ! Source du renvoi introuvable.**:

	Definition	Enactment	Improvement
Short term impact **Does the system learn something beneficial?**	• The light manpower that can be dedicated to the definition of the crisis scenario. • The lack of support equipment (only maps and plans) to create relevant exercises.	• The poor realism of the exercise due to the lack of special effects and real damages.	• The lack of concretely exploitable, significant, and capitalizable data except for some pictures and movies (in the best case).
Long term impact **Will the system remember what has been learned?**	• The difficulty to plan an exercise with the objective of making it a long term benefit, considering that this objective may seems secondary with regards to short term impact and relevance of the scenario.	• The low frequency of these exercises due to the actual disturbing impact on the site.	• The difficulty to mobilize the workforce after the exercise considering their impression of loss of time. • The lack of concretely exploitable, significant, and capitalizable data except for some pictures and movies (in the best case).
Inclusiveness **Are all the people that should be included, actually included?**	• The difficulty to expect a large "official" mobilization of the workforce considering the actual disturbing impact of such an exercise on the site.	• The practical difficulty to explain the scenario to a lot of people and to have them commit all together in it. • The low involvement of people due to the weak sensory impact of a simulated exercise on themselves.	• The difficulty to set up a transversal feedback process to generate "lessons learnt" and "significant benefits" on as much as possible sectors of the organization.
Coverage **Are all the scenarios that should be studied, actually studied?**	• The hard limits for the scenario that can be designed du to the fake aspect. • The complexity of including as many dimensions as possible in a one-shot realistic scenario.	• The low frequency of these exercises due to the actual disturbing impact on the site. • The complexity of running "live" a scenario that would include as many features as possible.	• The complexity of a fruitful analysis of the exercise with regards to all the relevant dimensions that should actually be considered.

Figure 3: The contributions of each of the four components on the limitations of real size exercises in critical sites

Basically, the previous figure shows that two components are more dedicated to the *definition* step (the *Exercise editor* and the *Virtual environment*), two are more dedicated to the *enactment* step (the *Virtual environment* and the *Decision support* tool), and finally one is more dedicated to the *improvement* step (the *Dashboard*).

OVERVIEW OF THE EGCERSIS RESEARCH PROGRAM

In this section, the architecture of the EGCERSIS platform is introduced more precisely.

The main scientific and technical obstacles of the EGCERSIS research program

Considering the objectives and associated components described in the previous section, the following barriers have been identified and must be considered by the EGCERSIS research program:

- Obtaining a relevant, trustable and continuously updated digital twin of the considered critical industrial site is absolutely mandatory and should be considered as an absolute requirement. Obviously, these digital twins should, in addition, be exploitable by the Virtual Reality environment (based on the Unity® framework[2]) chosen for the research program.
- Crisis management is, by essence, the world of the unexpected. More than anywhere else, instability is the norm. As a consequence, it should be possible for users, not only to define as various scenarios as they want (type of crisis, kinetics of the crisis, nature of the crisis, etc.) but also to intervene during runtime to change or update the scenario in order to optimize the training exercise. So, this is not only a question of the flexibility of the exercise editor (which is though crucial) but also a matter of dynamicity and openness of the Virtual environment.
- Moving crisis management training from the real world to the virtual world should not only include actual and current practices but also tools and technologies. As for example, if a communication, mapping or planning tool is the nowadays' reference in the world of responders (first aid, second aid or external), it must necessarily be integrated into the virtual world to optimize the training session.

[2] https://unity3d.com/

- The multi-player aspect is an unavoidable feature. It is so significant in the real world, where crisis management is foremost a collaborative issue, that it must be precisely and efficiently integrated into the virtual training platform. Besides, this collaboration aspect should cover on the one hand the human aspect (between two or more persons) and the service aspect (between two or more organizations).

Big picture of the EGCERSIS research program

To tackle the obstacles described in the previous sub-section, the EGCERSIS research program aims at performing the four main following steps as presented in Figure 4:

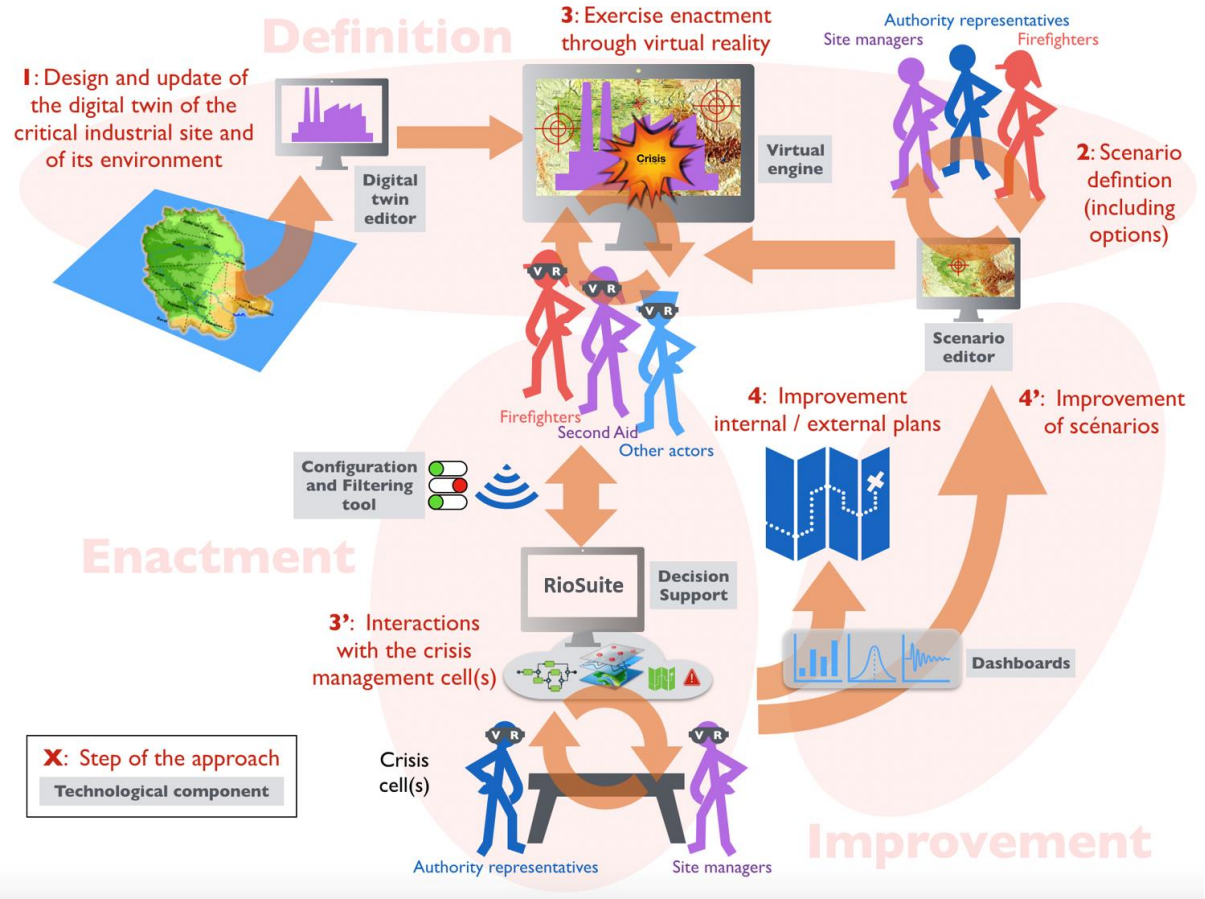


Figure 4: The big picture of the EGCERSIS outputs

1. Based on actual plans of the building (for instance the ones generally dedicated to being constantly updated in the crisis management plan of a SEVESO site) and on other inputs (crowdsourced map, private map, UVA, etc.) a 3D digital twin of the considered site should be defined within the dedicated editor.
2. The selected scenario and its characteristics (nature, timeline, kinetics, etc.) should be described in the dedicated scenario editor. This editor is to be used by authority representatives, site managers or responders. It should permit to create and implement a realist and adaptable crisis scenario. The idea would be to choose and implement a crisis scenario in a virtual reality digital twin of a chosen industrial site. One envisioned possibility is to be able to make the scenario evolve depending on the answers of the stakeholders who are solving the crisis.
3. Immersed in the virtual environment (through VR goggles), all the potential stakeholders (first aid, second aid, firefighters and other responders) do face the scenario and do experiment the exercise in a realistic environment as close as possible to the real site. Meanwhile, the crisis managers do deal with the crisis situation, using RIO-Suite as support for their decisions (RIO-Suite receive data directly from the simulation environment, filtered by a configuration panel presented in the perspective section).
4. Due to the numerical nature of the exercise, everything about the exercise and its dynamics may be

collected in real time. This is an amazingly positive point because it means that everything could be monitored and even replayed on demand to analyze, visualize and exploit the exercise. This should allow on the one hand to improve the exercise but of course, on the other hand, to improve the plan as a whole (including the skills and know-how of the people).

PERSPECTIVES OF THE EGCERSIS RESEARCH PROGRAM

From the point of view of the EGCERSIS research program, the potential results of the program would lead to a revolution in the domain of security and safety of industrial critical sites. Roughly speaking, the *frequency*, *quality*, *realism*, *coverage*, and *exploitability* of exercise could simultaneously be increased. This is definitely a very promising avenue for the improvement of (i) internal/external plans and (ii) efficiency/effectiveness of actors involved in crisis management (first and second aid as well as external responders). Such an improvement of the preparation phase of such critical industrial sites would consequently improve the resilience of the industrial system impacted. This perspective is clearly the most important of the EGCERSIS research program. Besides, it opens a full business market for Virtual Reality companies.

Another interesting avenue of the EGCERSIS research program is the possibility of having the virtual environment used for evaluating, testing, practicing not only plans and processes, but also new tools and new technologies. Actually, the virtual nature of the played exercise allows considering exploiting absolutely any type of data generated by the virtual environment. Thus, it would be of great benefit to check if the indoor geo-location of responders (which is a very trendy expectation that could completely and perfectly be simulated in the context of a virtual exercise) would help considerably or marginally crisis management. Similarly, it could also be very interesting to plug any new technological platform to the virtual environment (through a configuration and filtering tool, as presented in Figure 4, dedicated to simulating which data should actually be transmitted to the evaluated platform). For instance, within the EGCERSIS research program, it is planned to create and evaluate a new version of RIO-Suite. This version of RIO-Suite would be based on a virtual environment as well and would allow the decision makers to move in a virtual environment where the visualization and the decision-making would be easier. In this context, the configuration and filtering tool would be in charge to simulate what kind of data RIO-Suite should actually be fed with. The kind of data that RIO-Suite is able to use is presented in (Benaben et al.). The very interesting point is that all the data could entirely be obtained through the virtual environment.

The last perspective considered in this article concerns the extension to other exercises than the one in critical industrial sites. This first target is mainly due to the fact that these sites are legally obliged to run crisis management exercises and have consequently all the required material (plans, maps, scenarios, etc.) and a lot of interest for the EGCERSIS research program. However, if the process becomes seamless and effective, if the benefits are obvious and if the efficiency of preparation is clearly demonstrated, other sites could be considered: critical infrastructure (airport, train station, etc.), overcrowded site (touristic place, public building, university, etc.) and any place that potential users (responders but also homeland security stakeholders) would like to study.

CONCLUSION

The EGCERSIS research program is dedicated to creating a breakthrough in the way crisis management exercises are conducted. This domain of the *preparation* phase definitely suffers from a lack of effectiveness and efficiency. For years now, the classical yearly exercises, with simulated imaginary damages and casualties, have shown how disappointing they can be. These exercises, even if most of the time mandatory, are really far from the results they should bring. As a consequence, the *response* phase which is supposed to be a combination of a majority “implementation of the results of the preparation phase” and a minority “improvisation due to the specificity of the faced situation”, can often be considered as a majority “improvisation” and a minority “implementation”. Virtual Reality opens completely new perspectives: allowing, on the one hand, to replicate the real world to perform experiments in real size without any barriers, and on the other hand to forget about the real world in order to create completely free interfaces benefiting from the realistic physical environment but independent from the constraints of the real world. This new world of VR should be investigated with both these visions.

REFERENCES

Ardila, L., Perez-Llopis, I., Palau, C., Esteve, M. (2013) LVC Training Environment for Strategic and Tactical Emergency Operations, *Proceedings of the Tenth International Conference on Information System for Crisis Response and Management*, Baden-Baden, Germany.

Atlay, N., Green, W. (2005) OR/MS research in disaster operations management, *European Journal of*

Operation Research, Elsevier, 175, 1, 475-493, 2005.

Berndt, H., Wessel, D., Willer, L., Herczeg, M., Mentler, T. (2018) Immersion and Presence in Virtual Reality Training for Mass Casualty Incidents, *Proceedings of the Fifteenth International Conference on Information System for Crisis Response and Management*, Rochester, NY, USA.

Benaben, F., Fertier, A., Montarnal, A., Salatge, N., Truptil, S., Rebière, S., & Lauras, M. (2017). A Conceptual Framework and a Suite of Tools to Support Crisis Management. In *HICSS 2017-50th Hawaii International Conference on System Sciences* (pp. p-237).

Dolidon, H. (2018) Granularité des niveaux de pilotage en gestion de crise, *GeNePi project final report*, 91pages.

Dugdale, J., Pavard, B., Pallamin, N., El Jed, M., Maugan, L., (2004) Emergency Fire incident training in a virtual world, *Proceedings of the First International Conference on Information System for Crisis Response and Management*, Brussels, Belgium.

Gottmann, J. (1975) The Evolution of the Concept of Territory, *Social Science Information*, 14, 3, 29–47.

Hendela, A., Yao, X., Turoff, M., Hiltz, R., Chumer, M. (2006) Virtual Emergency Preparedness Gaming: A Follow-up Study. *Proceedings of the Third International Conference on Information System for Crisis Response and Management*, Newark, NJ, USA.

Radianti, J., Gil Martinez, S., Munkvold, B. E., Konnestad, M., (2018) Co-Designing a Virtual Training Tool for Emergency Management, *Proceedings of the Fifteenth International Conference on Information System for Crisis Response and Management*, Rochester, NY, USA.

Stewart, T. J. (1992) A Critical Survey on the Status of Multiple Criteria Decision Making Theory and Practice, *Omega* 20, 5, 569–586, 1992.

Wright, T., Madey, G., (2008) A Prototype Virtual Emergency Operations Center using a Collaborative Virtual Environment, *Proceedings of the Fifth International Conference on Information System for Crisis Response and Management*, Washington, DC, USA.

Yodo, N., Wang, P. (2016) Engineering Resilience Quantification and System Design Implications: A Literature Survey, *Journal of Mechanical Design* 138, 11, 111408-111413.

Zarraonandia, T., Bañuls, V., Aedo, I., Diaz, P., Turoff, M., (2014) A Scenario-Based Virtual Environment for Supporting Emergency Training, *Proceedings of the Eleventh International Conference on Information System for Crisis Response and Management*, State College, Pa, USA.

Track 15.

Open Track

Chairs,

José J. González, *University of Agder, Norway*

Hossein Baharmand, *University of Agder, Norway*

Understanding Aggregate Human Behaviour Changes in Response to a Natural Disaster in Vanuatu via Mobile Network Data Analysis

Rajius Idzalika
Pulse Lab Jakarta
rajius.idzalika@un.or.id

Yulistina Riyadi
Pulse Lab Jakarta
yulistina.riyadi@un.or.id

Imaduddin Amin
Pulse Lab Jakarta
imaduddin.amin@un.or.id

George Hodge
Pulse Lab Jakarta
george.hodge@un.or.id

Jong Gun Lee
Pulse Lab Jakarta
jonggun.lee@un.or.id

ABSTRACT

This paper presents a use case of mobile network data as a new source of insight for humanitarian action. Based on analysis covering the Republic of Vanuatu, we identify aggregate behavioral patterns indicating short term and medium term behavior changes as a result of a tropical cyclone, which could contribute to our understanding of the resilience of communities to natural hazards. We also find interesting behavioral insights on how the human movement network is impacted by a cyclone. Due to the detail and tractability of the data set, insights on preparation, displacement, damage and resilience could enable more agile and adaptive responses by public institutions and other actors to humanitarian emergencies. Considering the array of natural hazards that the South Pacific region faces on an annual basis, this use case contributes more evidence in favor of using anonymized mobile network data to inform humanitarian action.

Keywords

Vanuatu, mobile network data, humanitarian, disaster impact, tropical cyclones.

INTRODUCTION

This paper analyses mobile network data in the context of the Pacific island nation of Vanuatu, a Y-shaped archipelago with four main islands and 79 smaller islands (GFDRR, 2017). Vanuatu's geographical location contributes to the nation's exposure to a string of volcanoes, earthquakes and other seismic activities, as well as tsunamis, storms, tropical cyclones, coastal flooding and landslides. With such breadth and frequency of natural hazards, it is considered a country with a high degree of vulnerability. Due to the confluence of vulnerability, the availability of big data and a request for policy insights from the Government of Vanuatu, the country was selected as an appropriate context for this research.

Tropical Cyclone Donna impacted northern Vanuatu at the beginning of May 2017, with an early alert published on 3rd May. The tropical cyclone intensified to category three on 5th May, and to category five on 8th May. The

cyclone moved on from Vanuatu on 9th May. According to the UN Office for the Coordination of Humanitarian Affairs (2017) as of 8th May 2017, Vanuatu had experienced significant damage to housing and communication networks. During the tropical cyclone, the TVL mobile phone network was down in Torba Province in the north of Vanuatu. Tropical Cyclone Donna was unusual for the time of year, as May is not commonly an active month for cyclones.

The primary data source for this research project, mobile network data, is defined as the information elements contained in call detail records (CDRs) created by mobile network operators for billing purposes and summarising anonymous mobile users' activity, i.e. phone calls, text messages and data connections (UN Global Pulse, 2018), but contain no information on their content. As this data is uniquely detailed and tractable, it can capture information not easily found from other sources at a scale that would be difficult to recreate through other means (UN Global Pulse & GSMA, 2017). Once anonymized and aggregated to appropriate levels, mobile network data can provide a variety of insights with tremendous value for development and humanitarian action, including mobility, social interaction and economic activity (UN Global Pulse, 2013).

Using Tropical Cyclone Donna as a case study, we are interested in exploring how mobile network data capture aggregate behavior changes related to natural hazards, perhaps also revealing the resilience of communities to these events by the speed at which pre-disaster patterns re-emerge or the point at which new stable patterns emerge based on structural changes due to the shock. Alongside this general question, we are also interested in whether Tropical Cyclone Donna impacts the human movement network within and between islands. The use case is a tangible demonstration of how the data set can provide real value to policymakers and humanitarians by providing new insights at a higher degree of spatial granularity, at a higher frequency, in a timely manner, enabling more agile and adaptive responses by public institutions to both opportunities and challenges.

In examining aggregate behavioral patterns; we find short term and medium term behavior changes after Tropical Cyclone Donna. We identify four different classes of patterns related to behavior changes, which are increasing, decreasing, V shape, and other patterns. We also find interesting behavioral insights by processing the trajectories of anonymous mobile network users, developing our understanding of how the human movement network is impacted by a cyclone. Findings of note include the nature of inter- and intra-island human movements, both before and after Tropical Cyclone Donna, as well as the inference that the local population was taking action in anticipation of the tropical cyclone in advance of official alerts, and the observed surge in positive movement anomalies away from the Island of Ambae in Penama province on 7th May 2017, the day before the cyclone was classified as category five.

Our analysis of mobile network data complies with the Global System for Mobile communication (GSM) Association privacy guidelines for the use of mobile phone data (GSMA, 2014), originally developed in response to the Ebola outbreak in West Africa which occurred between 2013 and 2016. Specifically, the guidelines dictate that user data be anonymized, that user data not be transferred outside of the mobile network operator's systems, that all analysis take place on the mobile network operator's systems and under operator supervision, that no analysis be undertaken that singles out identifiable individuals, and that only the output of the analysis (i.e. the resulting non-sensitive data, aggregate statistics, indicators, etc.) be made available to relevant and approved aid agencies, government or research agencies that can use these inputs in their modeling and planning efforts.

RELATED WORKS

Scholars have been using various data sources and methods to understand human behaviours and movements during and after natural disasters or other types of crises. Recent developments in our understanding of these events have, in part, derived from new data sources, such as social media and Global Positioning System (GPS) records, which have enabled new insights at a finer degree of spatial and temporal granularity. Wang (2014) developed insights on human trajectories and movement patterns at high-resolution by mining Twitter data from New York City, during and for several days after Hurricane Sandy in 2012, calculating trip distance distribution, the radius of gyration of movements, and frequently visited locations. Meanwhile, Song et al. (2014) used the GPS records of 1.6 million users over one year to investigate and analyse human behavior during emergencies and their movements following the Great East Japan Earthquake and Fukushima nuclear accident.

The increasing use of mobile networks in developing countries also offers a rich source of insights for humanitarian action. Several scholars have explored the data set to meet humanitarian information needs, for example Bengtsson et al. (2011) estimated the net outflow of people from Port-au-Prince following the 2010

earthquake in Haiti by scaling insights from mobile network data via reference to the census. They also demonstrated the ability to produce rapid estimates of mobile network user movements during the Haitian cholera outbreak. Further research by Lu et al. (2012) showed that Port-au-Prince lost nearly a quarter of its residents nineteen days after the earthquake. Later research, again by Lu et al. (2016), mined mobile network data to develop insights on anomalies in communication, mobility and consumption during Cyclone Mahasen in Bangladesh. This research uses a novel approach to understanding human movements, developing time series insights on the number of mobile network users that move between the coverage areas of different cell towers, building our understanding of what the authors of this paper term a human movement network.

As highlighted in the introduction, above, mobile network data offers insights beyond human movements. De Montjoye et. al. (2016) developed an open-source toolbox for feature engineering of mobile network data, called bandicoot. The features fall into three categories: (a) anonymized individual information including the total number of calls, text response rate and others; (b) spatial information of each anonymous user such as radius of gyration, entropy of places visited; and (c) social network metrics such as clustering coefficient. For a comprehensive list and definition of these variables, please refer to the bandicoot website. Jahani et.al. (2017) and Felbo et. al. (2017) revealed that by combining bandicoot features and advanced machine learning, they are able to predict the demographic characteristics of the mobile network user population. Using similar feature engineering methods to understand behavioural changes in response to a series of earthquakes, Moumni et al. (2013) add to the literature on human movements and displacement post-disaster to examine the impact of an environmental shock on call volume, call duration and social activity. They find discernible differences in these metrics pre- and post-earthquake, although the paper analyses only two weeks of mobile network data spanning the Oaxaca Earthquake in 2012.

Gething and Tatem (2011) note that while the advantages of using mobile network data are self-evident, the limitations are weakly presented. They point out that severe natural hazards can damage mobile phone networks thus forestalling any analysis, and that when the networks are operational, the lower network coverage of sparsely populated regions makes it difficult to track displacement in rural areas. They also highlight issues connected to the representativeness of the data set, in that coverage errors and biases exist, and privacy issues regarding the mining of mobile network user data.

DATA

This paper pursues some of the research areas highlighted in the introduction and related works above, specifically insights on post-disaster aggregate behavior changes among mobile network users. In this analysis, we use anonymised call detail records generated between 1st January 2017 and 31st December 2017 and geo-located in Vanuatu. The mobile network data is accessed via a data partnership with Digicel, which holds a majority market share (TeleGeography, 2016). In 2015, Vanuatu hosted 104,000 unique mobile network users, representing approximately 40 percent of the country (GSMA, 2015); the market and the number of unique mobile network users is likely to have grown since then. By 2017, the overall mobile penetration of the population reached 80 percent of households (ITU, 2017).

There are hundreds of variables contained within one call detail record, such as transaction type, International Mobile Equipment Identity (IMEI) number, timestamp and tower ID, among others. We limit the data extraction to the variables commonly used in mobile network data analysis, namely: transaction type, transaction direction, caller id (anonymous), correspondent id (anonymous), tower id, call duration and a few others described in Table 1 below. We extract the raw data set by selecting only the specific columns of interest, highlighted in Table 1. Next, we perform data validation by selecting transactions that occur in Vanuatu, based on their antenna_id.

Mapping Tower Locations to Administrative Divisions

The call detail records are associated with cell towers; however, in some instances we require insights at different administrative levels, such as provinces or area councils. For this purpose, we conduct a reverse geolocation process for each tower, using the official shapefiles of administrative divisions from the Government of Vanuatu. In addition to this, we build a matrix of the distances between each of the towers, which is useful for analysing the human movement network. The following tables show the tower mapping information (Table 2) and sample data for the distance between towers (Table 3).

Table 1. Raw data

No	Column Name	Sample	Remark
1	caller_id	8f8ad28de134	
2	interaction	call	Call or Text
3	direction	in	In or Out
4	correspondent_id	fe01d67aeccd	
5	datetime	2017-01-02 08:13:17	

Table 2. Tower level information

No	Column Name	Sample	Remark
1	tower_id	31021	
2	lat	-17.7016944	
3	lon	168.3202806	

Table 3. Cell tower distances

No	Column Name	Sample
1	tower_id	31021
2	corresponding_tower	10305
3	distance	224.81

Generating Behavioural Indicators for Each Anonymous User

We use the bandicoot toolbox (de Montjoye et al., 2016) to extract hundreds of behavioral indicators, producing a weekly time series of the average of each indicator, from the raw data. If necessary, bandicoot can also return other statistical measures such as median, maximum, minimum, skewness and kurtosis, but we retain the default settings which return mean and standard deviation. We use bandicoot because it provides a simple approach to extract diverse features from mobile phone metadata that otherwise would be complicated and time-consuming.

We aggregate all the raw transactions at a weekly level following the ISO-8601 standard (a week starts on Monday and ends on Sunday). For each week, we develop behavioural indicators for each anonymous user that made a transaction during that week. To investigate aggregate behavior changes in response to Tropical Cyclone Donna, we focus on the variables developed by the bandicoot library that provides anonymized indicators at the individual level, divided into five broad categories: basic phone use, active users behaviors, location, regularity and diversity. We take the mean, and when available the standard deviation, of each variable for all anonymous users per week, then exclude variables that have missing values or that exhibit flat figures, i.e. all ones or all zeros, for the timeframe of the analysis, for which we use data from January to December 2017.

Transforming User Trajectories into a Human Movement Network

To understand human movement patterns, we transform the raw data format into a sequence of user transactions, which gives us the trajectory of an anonymous user, see Table 4 for an example. From the transactions described in Table 4, we create new columns by shifting the transactions, using the n+1 transaction as the Next Tower ID and produce Table 5, which includes the distance between the pairs of cell towers by comparison to the cell tower distance matrix. This table can then be used to create an aggregate human movement network at different levels of spatial and temporal aggregation, we choose a daily resolution for the time series.

The human movement network does not retain the trajectories of users, instead it captures the number of users moving between the coverage areas of each origin-destination pair of cell towers within the network, based on sequential transactions by users on the mobile network. It retains the distance between the origin-destination pairs of towers as an attribute. These data processing steps have the effect of undersampling anonymous users who make few transactions, because it is not possible to calculate a trajectory from one or no data points at the resolution of the time series. In turn, this results in a bias towards active users, as only their movements would be

detected. Thus, when using the terms "human movements" and "the human movement network", we are not generalising to the entire population of Vanuatu, but referring to the movements of active Digicel mobile network users.

Table 4. User level information

No	User ID	Date	Tower ID
1	8f8ad28de134	2017-01-01	31021
2	8f8ad28de134	2017-01-01	23005
3	8f8ad28de134	2017-01-01	50003

Table 5. Distance of two towers to build administrative level data

No	User ID	Date	Tower ID	Next Tower ID	Distance
1	8f8ad28de134	2017-01-01	31021	23005	4.8
2	8f8ad28de134	2017-01-01	23005	50003	269

We process the mobile network records for the first 20 weeks of 2017, a time frame covering 2nd January to 21st May. From this data set, we extract the ten weeks running up to the week of the early alert for Tropical Cyclone Donna, a time frame covering 20th February to 30th April 2017, from which we construct the human movement network for ten 'normal' instances of each weekday. This gives us a basis for comparison when examining the human movement network during Tropical Cyclone Donna.

METHODS

We examine the impact of Tropical Cyclone Donna by detecting behavioral changes, first, as articulated by indicators drawn from mobile network data, and second, based on shifts in the human movement network within Vanuatu.

Analysing Behavioural Changes

We conduct a preliminary analysis by filtering only the numeric variables from the bandicoot software, as well as binary variables that mostly come from reporting features (TRUE/FALSE converted into 1/0). We further examine them through exploratory data analysis. The variables that demonstrate significantly different patterns after the disaster are the best candidates for tracking behavioural changes. They are subject to further analysis.

To check the robustness of the exploratory data analysis, for each variable, we develop a forecast to provide an estimation of the future short term trend assuming that the tropical cyclone did not occur. We (partially) mitigate seasonality by excluding the first week of the year from the forecast[1]. Having said this, we do not claim the behavioral differences at the aggregate level are as a direct impact of tropical cyclone. But if the actual short term trend differs from the forecast, we investigate how the pattern behaves over the longer term. If it maintains some distance or pushes away from the pre-disaster and forecast trend, we conclude that behavioral changes are more likely to have taken place.

Information from weeks two to 17 is used to forecast the point estimation, 80 percent and 95 percent confidence band of weeks 18 to 23. The *ets* package in R builds a fully automated forecast system as the default, which we use (Hyndman et al., 2008). The model is not specified, adjusting for each specific time series type. The default of the optimization criterion is log-likelihood. As an example, the simplest likelihood function of Autoregressive model of order p - called AR(p) - is defined as follows:

[1] Other potential seasonality components are not strongly identified during the first quarter of the year.

$$\ln(L) = -\left(\frac{T-p}{2}\right)\ln(2\pi) - \left(\frac{T-p}{2}\right)\ln(\sigma^2) - \left(\frac{1}{2\sigma^2}\right)\sum_{t=p+1}^{T}[\phi(L)y_t]^2$$

Figure 1 displays an example of a forecast result which assumes that the tropical cyclone did not take place, which can be used for further analysis of the trend. Comparing it with the actual trend, as in Figure 2, both figures provide useful evidence of whether behaviour changes have occurred.

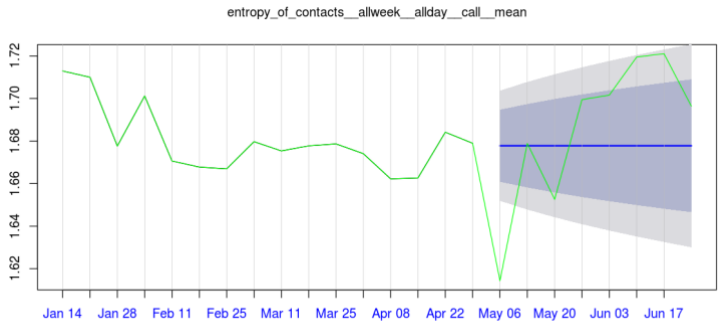


Figure 1. Example of short term forecasting. The blue line is the point estimation. Confidence bands are 80 percent (dark grey) and 95 percent (grey). Some part of the actual trend overlaps with upper limits of the 95 percent confidence band which merits further investigation.

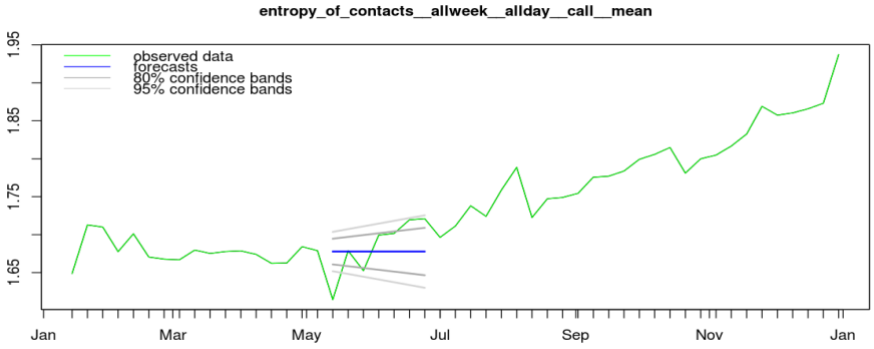


Figure 2. Example of the full year pattern in 2017. The pattern finally leaves the confidence bands, indicating evidence of longer term change in behaviour.

Analysing the Human Movement Network

As described above, we develop a human movement network for each day during the ten weeks running up to the week of the early alert for Tropical Cyclone Donna, as well as the three weeks covering Tropical Cyclone Donna and its aftermath, a time frame including 1st to 21st May 2017.

To gain a broad sense of the changes in the human movement network connected to the tropical cyclone, we multiply the directional weight associated with an origin-destination pair of cell towers (the number of users with sequential transactions connected to the origin-destination tower pair) by the distance between them and then sum at province level. Figure 7 displays the representations of the total distance traveled within each Province by the active mobile network users for a day of interest during Tropical Cyclone Donna and the ten instances of the same weekday during the ten weeks running up to the week of the early alert.

To examine changes in the human movement network at higher-resolution, we compute the z-score for the directional weight associated with an origin-destination pair of cell towers, which represents the number of standard deviations by which the value of the directional weight between a pair of cell towers on the day of interest

during Tropical Cyclone Donna is above or below the mean value of the directional weight between the same pair of cell towers for the ten instances during the ten weeks leading up to the week of the early alert for the tropical cyclone. We filter the z-score matrix for the day of interest during Cyclone Donna, to exclude z-scores between -3 and 3; z-scores above and below these values we define as anomalies. This generates a matrix of human movement network anomalies which we project onto a Map of Vanuatu for further visual analysis (see Figure 8).

FINDINGS

Patterns in Aggregate Behavioural Changes

Some variables developed from mobile network data using the bandicoot library seem to show distinctive trends after Tropical Cyclone Donna. Those trends are an initial signal of behaviour changes, but these changes are not, per se, the direct result of the tropical cyclone. Such trends should be observed more carefully, such as removing potential seasonality if there is strong evidence of its existence, and over a longer period of time to conclude that behaviour has changed as a result of the tropical cyclone.

We determine to work with 39 numeric/binary variables based on the preliminary analysis. From the method described above, we identify four major patterns of behaviour change after Tropical Cyclone Donna across 29 variables: 11 variables display an increasing trend, seven variables show a decreasing trend, eight variables demonstrate a V-shaped pattern, three variables uncover other patterns including an inverted V-shape pattern. Ten variables do not reveal significant patterns, so we exclude them from the analysis. Details of bandicoot variables used in this study are presented in Table 6-9.

There is a possibility that non-constant pre-disaster trends are affected by seasonal patterns and it might be better to only consider post-disaster patterns. Unfortunately, we do not posess data from other years to examine the seasonalities, therefore we stick to distinguishing patterns by considering pre-disaster trends as well. We focus our discussion on the average of each trend, and later on we include a small section dedicated to discussing the standard deviation.

The first pattern we discuss is the increasing trend (Figure 3, Table 6). The increasing trend is defined as showing a stable pattern prior to the tropical cyclone, then a rising pattern over time thereafter. Among the eleven variables with increasing trends, four relate to the diversity category (entropy of call contacts, call interactions per contact, variability of call interactions per contact, number of call contacts), five are related to the basic phone use category (number of outgoing call interactions, number of incoming call interactions, total number of call interactions, number of outgoing text interactions, and total number of text interactions) and two of them are reporting variables (number of records and if the records contain a call)[2].

The increasing amount of interactions, in particular outgoing calls and texts, could be a reflection of how the affected people and potentially the entire country copes with the shock. Moreover, users do not only increase the intensity of the interaction, but they also diversify their social network base by demonstrating a higher number of call contacts and higher entropy of contacts[3]. The causes of these changes in behaviours could be for information seeking or resource mobilisation. Our findings support the study on the Oaxaca earthquake by Moumni et al. (2013) where people made calls more often and carried out mobile interaction with more people around the time of the disaster. Additionally, the variability of interaction per call contact increases, which indicates that this feature is less predictable post-disaster.

We assume that the increasing trend of call diversity indicators and the basic phone use category indicators will at some point in time change, leading to two potential future outcomes: (i) a peak after which a downward trend follows, possibly after full recovery takes place, or (ii) users find a new equilibrium of higher diversity.

A decreasing trend is the second major pattern of interest (Figure 4, Table 7), where relatively constant behavior before Tropical Cyclone Donna shifts to a declining pattern post-disaster. There are seven variables displaying a

[2] More information on these metrics can be found in deMontjoye et al. (2013)

[3] For mobile network data, entropy is defined as the distribution of interaction across different contacts. Higher entropy indicates more equally balanced interactions with a large number of contacts (de Montjoye et.al., 2013).

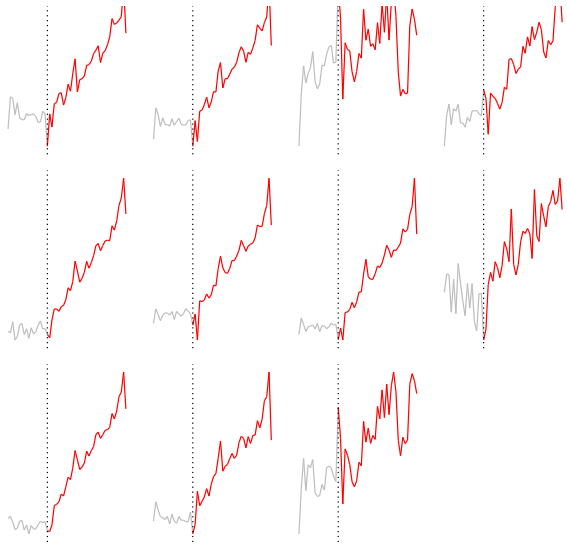


Figure 3. Eleven variables displaying an increasing trend after Tropical Cyclone Donna, which is represented by the dotted line.

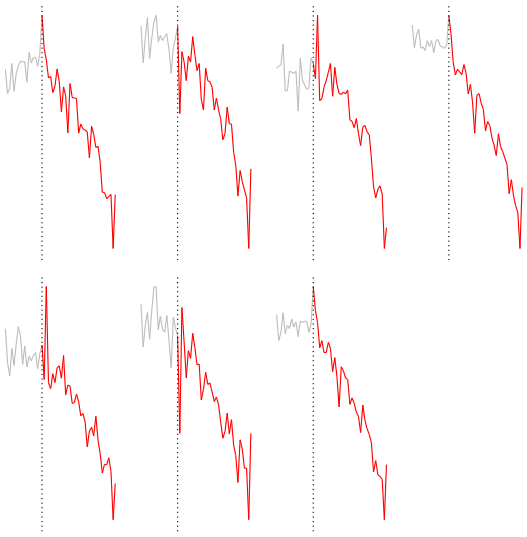


Figure 4. Seven variables displaying a decreasing trend after Tropical Cyclone Donna, which is represented by the dotted line.

Table 6. List of bandicoot variables with increasing trend

Variables with increasing trends after cyclone Donna	Definition
entropy_of_contacts__allweek__allday__call__mean	The entropy of the user's contacts on call.
interactions_per_contact__allweek__allday__call__mean__mean	The number of calls a user had with each of its contacts mean
interactions_per_contact__allweek__allday__call__std__mean	The number of calls a user had with each of its contacts SD of mean
number_of_contacts__allweek__allday__call__mean	The number of contacts the user called with.
number_of_interaction_in__allweek__allday__call__mean	The number of incoming calls.
number_of_interaction_out__allweek__allday__call__mean	The number of outgoing calls.
number_of_interaction_out__allweek__allday__text__mean	The number of outgoing text
number_of_interactions__allweek__allday__call__mean	The number of calls.
number_of_interactions__allweek__allday__text__mean	The number of text.
reporting__number_of_records	The number of records
reporting_has_call	The record contain calls

Table 7. List of bandicoot variables with decreasing trend

Variables with decreasing trends after cyclone Donna	Definition
balance_of_contacts__allweek__allday__call__mean__mean	The balance of calls per contact mean
balance_of_contacts__allweek__allday__call__std__mean	The balance of calls per contact SD of mean
interevent_time__allweek__allday__call__mean__mean	The interevent time between two calls of the user mean
interevent_time__allweek__allday__call__std__mean	The interevent time between two calls of the user SD of mean
percent_initiated_interactions__allweek__allday__call__mean	The percentage of calls initiated by the user.
percent_pareto_durations__allweek__allday__call__mean	The percentage of user's contacts that account for 80% of its total time spent on the phone.
percent_pareto_interactions__allweek__allday__call__mean	The percentage of user's contacts that account for 80% of its calls.

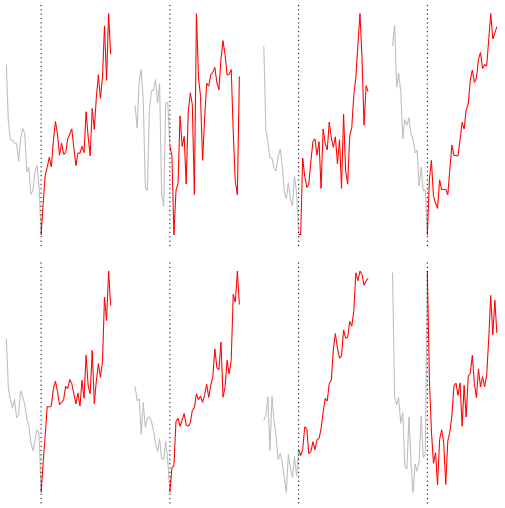


Figure 5. Eight variables displaying a V-shaped pattern, linked to Tropical Cyclone Donna, which is represented by the dotted line.

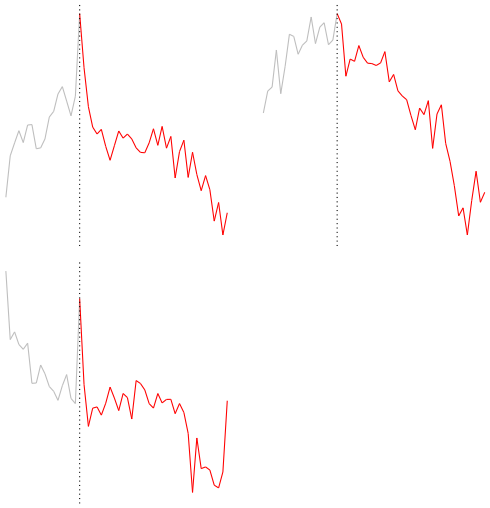


Figure 6. Three variables displaying other patterns including an inverted V-shape pattern, linked to Tropical Cyclone Donna, which is represented by the dotted line.

Table 8. List of bandicoot variables with V-shape trend

Variables with V shape trends after cyclone Donna	Definition
balance_of_contacts__allweek__allday__text__mean__mean	The balance of text per contact mean
balance_of_contacts__allweek__allday__text__std__mean	The balance of text per contact SD of mean
call_duration__allweek__allday__call__std__mean	Duration of call SD of mean
interactions_per_contact__allweek__allday__text__std__mean	The number of interactions a user had with each of its contacts.
interevent_time__allweek__allday__text__mean__mean	The interevent time between two text of the user.
number_of_interaction_in__allweek__allday__text__mean	The of number of text received.
percent_nocturnal__allweek__allday__call__mean	The of percentage of calls the user had at night.
percent_nocturnal__allweek__allday__text__mean	The average percentage of texts the user sent at night.

downward pattern that sit under three of the indicator categories: regularity (call inter-event time, and call inter-event variability), active behaviors (percent of calls initiated) and diversity (balance of call contacts, balance of call contacts variability[4], call percent pareto and total interactions percent pareto), some of which complement the insights from variables displaying an increasing trend.

For example, decreasing inter-event time is a natural consequence of a higher number of interactions. Additionally, the decreasing trend for balance of call contacts, percent initiated call interactions, percent pareto call duration and percent pareto call interaction, which exhibit opposite trends to other indicators in their categories, is a product of the scale free nature of the network. The absence of the indicator on call duration post-disaster among the indicators showing a declining pattern does not support the finding of Moumni et al. (2013). Finally, call balance of contacts and call inter-event time of show decreasing variability over time; this evidence adds more confidence to their central tendency post-disaster.

The V-shaped pattern (Figure 5, Table 8) represents a downward trend in the variable of interest prior to the tropical cyclone, that switches to an upward trend thereafter. In other words, this trend performs a sharp quadratic shape with a local minimum. We find this pattern for four metric categories: diversity (balance of contacts of text and balance of contacts of text variability), regularity (call duration and text interactions per contact variabilities, text inter-event time), basic phone use (total number of text) and active users behaviors (percent nocturnal of call and text).

[4] Balance of contatcs represents the fraction of outgoing interactions out of the total interactions (Almatouq et al., 2016)

Unlike the previous trends that are relatively constant pre-disaster, features with a V-shaped pattern already display a declining trend before Tropical Cyclone Donna. Text indicators for balance of contact, inter-event time, number of interactions and percent nocturnal decreased pre-disaster and increased post-disaster. In general, this evidence suggests that a disaster such as a tropical cyclone plays a role in returning texting behavior back into the mainstream of mobile communication. This is a new insight that is not revealed in previous studies. From the charts in Figure 5, most portray a clear V-shape, but the chart in the bottom right corner, representing the percent nocturnal of texts, actually displays a W-shaped pattern, which merits further investigation. The percent nocturnal for calls delivers another new insight that a disaster like a tropical cyclone could contribute to a shift towards evening phone calls.

The V-shaped pattern of the variability indicators (standard deviation) suggests that the dispersion of data points for the linked indicators shrank to the center around the time of the tropical cyclone, then the dispersion returned to normal levels following the recovery process. Indicator variabilities are usually not a major focus because they are nuance parameters; however, knowing that some features have non-constant variance is sometimes useful when implementing model adjustment.

We observe two final patterns: inverted V-shape and inverted decreasing (decreasing pre-disaster then constant post-disaster) displayed in Figure 6 and Table 9. We find that entropy of text contact (diversity category) and percent initiated call and text (active users behaviors category) rise pre-disaster, peaking around the time of Tropical Cyclone Donna and then decline post-disaster.

Inverted decreasing is found for the indicator on the percentage of interactions while at home (active users behaviors category, Figure 6, bottom left corner). The sustained nature of this trend may be due to infrastructure damage and the need for repairs to personal property as a result of the tropical cyclone, keeping users at home, as well as other social factors. If so, this could be an important variable to investigate and track following a natural disaster, as a measure of recovery time. Ground truth insights such as the location of damaged antennas are required to validate this intuition.

The overall findings suggest that given a natural hazard, call related metrics are more likely to produce either a longer term quadratic pattern or find a new equilibrium different to pre-disaster levels, as suggested by the increasing patterns. Meanwhile, text related metrics tend to show a short term quadratic behavior with more features following V-shaped and inverted V-shaped patterns. In our study, those patterns are not precisely correlated with the tropical cyclone; however, text behaviors might be useful for monitoring short term vulnerability, and further research on this observation is merited.

Meanwhile, resilience is both demonstrated and developed by "bouncing forward" (Manyena et al., 2011; Houston et al., 2015) as a positive consequence of successful adaptation to shocks and hardship. Through this lens, increasing patterns defined in this study are promising as the proxy indicators of resilience. We find two longer term possibilities, either the indicator returns to pre-event levels or it finds a new equilibrium at a different level. The time it takes to return to previous levels or to stabilise at the new normal is likely a good measure of resilience, but further contextual research is required on which patterns indicate higher resilience. We do not find strong evidence that predefined categories of indicators exclusively fall into a certain pattern. Another approach such as cluster analysis or principal component analysis might be an alternative to group the indicators into specific patterns in a more compact fashion.

Recent literature recognizes that communication is one of the elements of adaptive capacity (Norris et al., 2008; Pfefferbaum et al, 2015; Houston et al. 2015; Houston, 2018). Borrowing these framework, we argue that our findings on various patterns of human behaviors via mobile network data indicates a promising research agenda on further exploring mobile communications as proxy indicators for vulnerability, adaptive capacity and community resilience.

Changes in the Human Movement Network

By comparing the aggregate distance travelled by active mobile network users within each province for the ten weeks preceding the week of the early alert for Tropical Cyclone Donna with Monday 8th May (the day on which Cyclone Donna intensified to category five, which is displayed as a red diamond in Figure 7), it is clear that the impact on the human movement network is sizeable for the provinces near the eye of the tropical cyclone, as articulated by the aggregate distance travelled being well outside the range during 'normal' times.

Table 9. List of bandicoot variables with other trends

Variables with other shapes/trends after cyclone Donna	Definition
entropy_of_contacts__allweek__allday__text__mean (inverted V shape)	The entropy of the user's contacts on text.
percent_initiated_conversations__allweek__allday__callandtext__mean (inverted V shape)	The percentage of conversations (calls and text) that have been initiated by the user.
percent_at_home__allweek__allday__mean (constant after decreasing)	The percentage of interactions the user had while he was at home

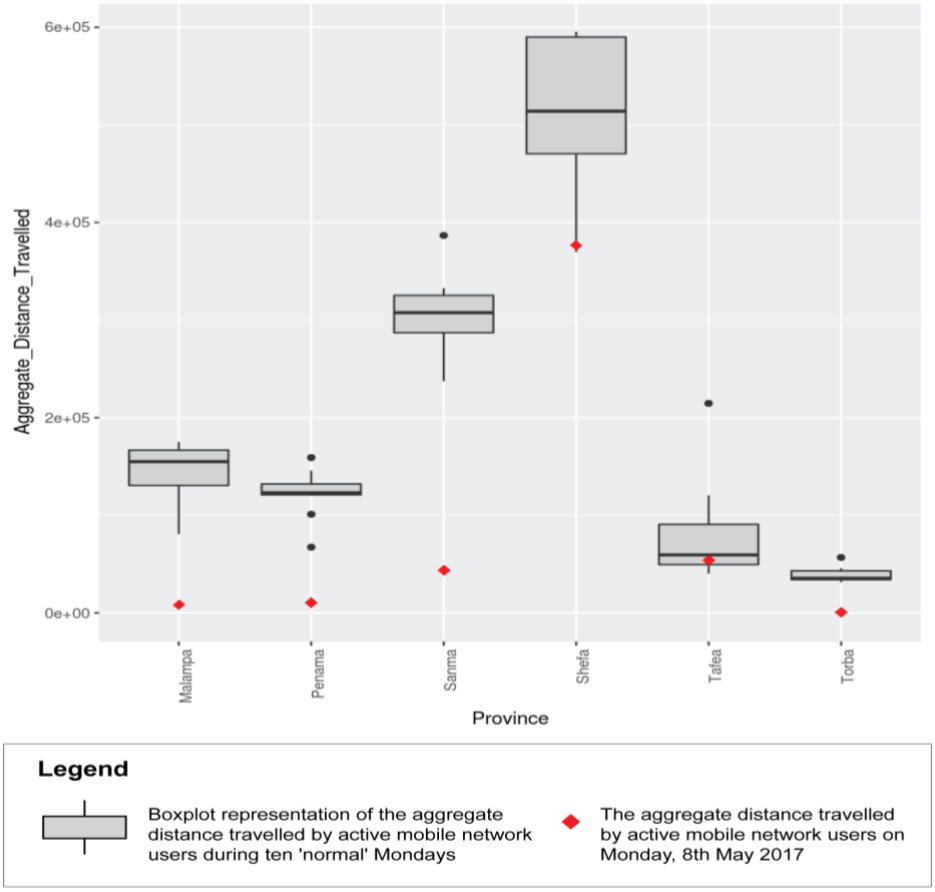


Figure 7. Human movements by province: aggregate distance travelled

The provinces of Torba, Sanma, Penama and Malampa all display diminished aggregate human movements on 8th May, well outside of the normal range captured by the boxplots in Figure 7. This finding is consistent with the trajectory and impact of the tropical cyclone described in the situation reports from the National Disaster Management Office of the Government of the Republic of Vanuatu (2017) and the UN Office for the Coordination of Humanitarian Affairs (2017). After crossing above Torba province in the north of the archipelago, the tropical cyclone headed south, along with the west coast of Vanuatu, hugging the western edge of the provinces of Sanma and Malampa.

The human movement network anomalies, generated for each day during the three weeks from 1st to 21st May 2017, add to our understanding of human movements before, during and after Tropical Cyclone Donna. Figure 8 shows these anomalies from four days of interest projected onto a map of Vanuatu: negative anomalies in human movements or an anomalous decrease in human movements are displayed in red, and positive anomalies in human

movements or an anomalous increase in human movements are displayed in blue, with the width of the line signifying the size of the anomaly.

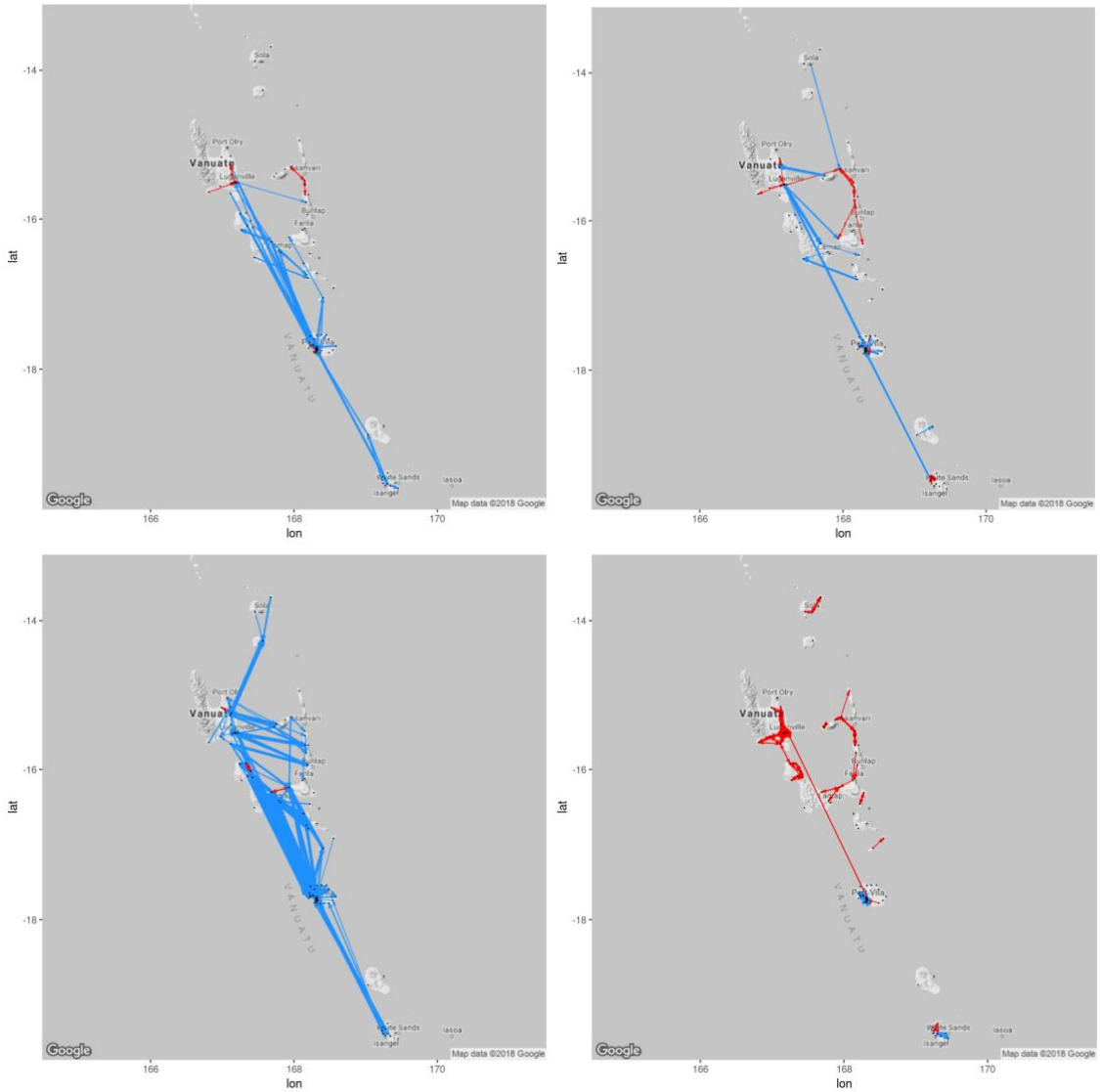


Figure 8. Human movement network anomalies pre-, during and post-Tropical Cyclone Donna (red = negative anomaly in human movements or an anomalous decrease, blue = positive anomaly in human movements or an anomalous increase; clockwise from the top left, 1st, 3rd, 8th and 12th May).

An early alert for Tropical Cyclone Donna was issued by the Fiji Meteorological Service on 3rd May 2017 (Vanuatu Red Cross Society, 2017); however, based on the human movement network anomalies, 1st May witness significant positive anomalous movements *into* Port Vila, the capital, and 2nd May witnessed significant positive anomalous movements *out of* Port Vila. These movements could represent people migrating to safer locations to sit out the storm, or returning from business trips early to protect loved ones and assets. Either way, it seems that some members of the local population were already acting in anticipation of the tropical cyclone.

From the day of the early alert on 3rd May until 7th May, we see broadly an increase in negative human movement network anomalies *within* the islands of the northern provinces and an increase in positive human movement network anomalies *between* the islands of the northern provinces, as well as predominantly positive human movement network anomalies in the southern provinces of Shefa and Tafea. Of note, on 5th May, the day on which Digicel sent text blast to all users warning of Tropical Cyclone Donna (Food Security Cluster, 2017), we see a step increase in negative human movement network anomalies within the islands of the northern provinces, and on 7th May we witness a surge in positive human movement network anomalies away from the Island of Ambae in Penama province. This suggests that the mobile data is capturing two behaviors: reduced movement

due to the cyclone, and evacuation. The increase in within island human movements in the southern provinces could be explained by the increase in population on these islands caused by evacuations from the northern provinces, or due to improved sampling caused by increased mobile network usage linked to the natural hazard.

As can be seen from the bottom-right image in Figure 8, the human movement network anomalies on Tropical Cyclone Donna's most intense day, 8th May 2017, on which it was classified as a category five tropical cyclone, are uniformly negative for the northern provinces, and predominantly positive for the southern provinces. As with the preceding days, the increase in within island human movements in Port Vila could be explained by the increase in population on this island caused by evacuations from the northern provinces, or by increased activity on the mobile network improving the detection of human movements on the island.

On 9th May, human movement network anomalies *within* the islands of the northern provinces remain negative; however, we also see the return of positive human movement network anomalies *between* the islands. This trend of positive human movement network anomalies between the islands increases on 10th May, with diminished within island negative human movement network anomalies. The trend of positive human movement network anomalies between islands continues until 21st May and possibly beyond, with a climax on 12th May, as highlighted by the bottom left image in Figure 9. The within island negative human movement network anomalies reverse to positive by 11th May but return to negative on 18th May until the end of the study period on 21st May, this trend is especially clear in Sanma province. With the increase in positive human movement network anomalies between the islands, especially between Port Vila and the northern provinces, we may be detecting both the return of evacuees and the beginning of the response effort. Regarding the within island behaviour, especially in Sanma province, we may be witnessing an initial boost to human movement due to evacuation or return post-tropical cyclone, followed by negative human movement as reconstruction efforts begin and damaged infrastructure suppresses all non-essential movement.

As highlighted above, it is also possible that some of the fluctuations in positive human movement network anomalies pre- and post-cyclone are a result of the improvement in sampling caused by greater use of the mobile network at that time. It is clear from the section on aggregate behavioural changes, above, in particular the increasing trend in the indicators under the *basic phone use* category, for example the indicator on the total number of interactions, that the network is experiencing higher usage connected to the tropical cyclone. For negative human movement network anomalies this is unlikely to be the case, as if the above observation is true, they appear in spite of the additional sampling and can therefore be analysed with more confidence. As highlighted in the section on data processing, due to the data scarcity relative to GPS-based trajectory data, active users shape the signal more than less active users, resulting in coverage bias, thus we make no attempt to generalise the findings to the entire population of Vanuatu. In addition, the patterns of human movements intra- and inter-island make the case study specific to an archipelagic context. We would expect to find different human movement trends and structure to the human movement network on a larger island or in a continental country.

Nonetheless, in an archipelagic context, the ability to detect persistent negative human movement network anomalies can be of use to humanitarians for identifying areas struggling to recover from natural disasters and for the targeting of assistance on this basis. The frequency and granularity of the data set, in particular, offers a step change in the speed of feedback on the efficacy of humanitarian assistance, which could enable more efficient resource allocation. This potential invites further exploration of insights from mobile network data in an operational context.

CONCLUSION AND FURTHER RESEARCH

Due to its detail and tractability, mobile network data holds the potential to inform humanitarian operations, especially in periods of high uncertainty in the hours, days and sometimes weeks following a natural disaster. The observed coverage errors and biases in the data set can be addressed with calibration methods by reference to the census, but these often require either good quality subscriber identity module (SIM) registration data, or a tele-survey of a random sample of the network subscriber base. Thus for the foreseeable future, mobile network data insights can complement traditional data collection methods common in the humanitarian sector. The research findings described above focus on general sense-making and anomaly detection with the mobile network data, functions for which full representativeness is desired but not required, and so offers value to humanitarian operations in archipelagic contexts.

Our identification of aggregate patterns indicates short term and medium term behavior changes after Tropical Cyclone Donna. We identify four different classes of patterns in the bandicoot variables related to behavior changes, which include increasing, decreasing, V-shaped, and other patterns. Patterns generated from text activities, although not exclusively, tend to revert to the pre-event levels. Patterns produced by call activities are more intriguing, since the indicators displaying increasing patterns show a potential longer term convergence that exceeds our study period. There are two potential future states, either a long term bouncing back to pre-disaster levels or a new equilibrium. Both cases are interesting because they offer potential as a measure of community resilience, both in terms of the return to stable states and the time it takes to achieve stability, as well as to inform the targeting of resources by governments and humanitarian agencies.

We also find interesting behaviors by processing the trajectories of anonymous mobile network users, creating insights on aggregate human movements. Findings of note include the nature of inter- and intra-island human movements, both before and after Tropical Cyclone Donna. These movements by a cohort of the local population at different stages during the crisis were hypothesized to represent people migrating to safer locations to sit out the storm, returning from business trips early to protect family members and assets, the return of evacuees and the beginning of humanitarian assistance and the reconstruction effort. Exactly where and when these activities contribute to the observed human movement network anomalies requires greater contextual knowledge and further research. It should be highlighted that the insights cannot be applied to the general population due to the absence of universal coverage of the mobile network and hence the possible presence of coverage bias. For example, due to the cost of using mobile network services, it is likely that the dataset is more representative of wealthier socioeconomic cohorts than the population at large. As highlighted above, this issue could be addressed by surveying a random sample of mobile network users and then calibrating the insights from the research by reference to the census.

In terms of further research on the general behavioral patterns based on the bandicoot variables, it would be interesting to compare behaviour changes connected with different natural hazards: for example, do differences exist between sudden onset hazards like earthquakes and relatively slower onset hazards like cyclones. The existing body of research suggests that this may be the case. The second area of further research could analyze regional level patterns, in particular comparing more and less severely impacted areas. This research could investigate the presence of causal links between the tropical cyclone and longer-term changes in behavior. A more rigorous conclusion would be expected if there are meaningful trend differences between Torba province, which was closest to the eye of the tropical cyclone, and other regions well beyond the reach of the storm, although the near-closed system status of an archipelagic country would complicate such an analysis. Since Tropical Cyclone Donna happened at an unusual time, it would also be interesting to compare the results with findings from other tropical cyclones that occurred during what is traditionally the cyclone season.

Regarding human movements, it would be interesting to examine population and mobile network user distribution, and tower-level activity to understand the positive human movement network anomalies in the southern provinces throughout the study period. Further research in this specific area should also include the use of a centroid-based human movement matrix gridded at a certain resolution or administrative level, as the tower-level human movement matrix used in this research may not capture human movement patterns as optimally. More sophisticated anomaly detection methods would be beneficial, as well as awareness of the possibility that tower or grids pairs which experience negligible flows during normal times produce anomalies based on only a small increase in the actual human movements between the two locations. In addition, it would be interesting to examine mathematically the correlation between the trajectory of the cyclone and decreased active human movements, as well as correlating aggregate mobile network activity volume with cyclone landfall. Exploring any differences in behavior between littoral and in-land communities could hold potential. It would also be interesting to conduct a network analysis of aggregated call and text activity to understand how the cyclone impacted behavior at this level, as well as investigate whether anomalies in airtime credit purchases in advance of the cyclone predict exposure to previous tropical cyclones or other natural hazards.

REFERENCES

Almaatouq, A., Prieto-Castrillo, F., & Pentland, A. (2016). Mobile communication signatures of unemployment. In *International conference on social informatics* (pp. 407-418). Springer, Cham.

Bengtsson, L., Lu, X., Thorson, A., Garfield, R., & Von Schreeb, J. (2011). Improved response to disasters and outbreaks by tracking population movements with mobile phone network data: a post-earthquake geospatial study in Haiti. *PLoS medicine*, *8*(8), e1001083.

de Montjoye, Y. A., Quoidbach, J., Robic, F., & Pentland, A. S. (2013, April). Predicting personality using novel mobile phone-based metrics. In *International conference on social computing, behavioral-cultural modeling, and prediction* (pp. 48-55). Springer, Berlin, Heidelberg.

de Montjoye, Y. A., Rocher, L. and Pentland, A. S. (2016) bandicoot: a Python Toolbox for Mobile Phone Metadata, *Journal of Machine Learning Research,* 17, 175, 1-5.

Food Security Cluster (2017, May 8). TC Donna FSAC Meeting #3. Retrieved from: http://fscluster.org/vanuatu/event/tc-donna-fsac-meeting-3

Gething PW, Tatem AJ (2011) Can Mobile Phone Data Improve Emergency Response to Natural Disasters? PLoS Med 8(8): e1001085. https://doi.org/10.1371/journal.pmed.1001085

GFDRR (2017). Vanuatu. Retrieved from: https://www.gfdrr.org/en/vanuatu

GSMA (2014) GSMA guidelines on the protection of privacy in the use of mobile phone data for responding to the Ebola outbreak. Retrieved from: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/11/GSMA-Guidelines-on-protecting-privacy-in-the-use-of-mobile-phone-data-for-responding-to-the-Ebola-outbreak-_October-2014.pdf

GSMA (2015) The Mobile Economy Pacific Islands 2015. Retrieved from: https://www.gsmaintelligence.com/research/?file=23485245295f02524925b2bd3aeec6de&download

Houston, J. B., Spialek, M. L., Cox, J., Greenwood, M. M., & First, J. (2015). The centrality of communication and media in fostering community resilience: A framework for assessment and intervention. *American Behavioral Scientist*, *59*(2), 270-283.

Houston, J. B. (2018). Community resilience and communication: dynamic interconnections between and among individuals, families, and organizations. *Journal of Applied Communication Research*, *46*(1), 19-22.

Hyndman, R., Koehler, A. B., Ord, J. K., & Snyder, R. D. Forecasting with Exponential Smoothing: The State Space Approach. 2008.

ITU (2017) Measuring the Information Society Report 2017, Volume 2. Retrieved from: https://www.itu.int/en/ITU-D/LDCs/Documents/2017/Country%20Profiles/Country%20Profile_Vanuatu.pdf

Jahani, E., Sundsøy, P., Bjelland, J., Bengtsson, L., & de Montjoye, Y. A. (2017). Improving official statistics in emerging markets using machine learning and mobile phone data. *EPJ Data Science*, *6*(1), 3.

Lu, X., Bengtsson, L., & Holme, P. (2012). Predictability of population displacement after the 2010 Haiti earthquake. *Proceedings of the National Academy of Sciences*, *109*(29), 11576-11581.

Lu, X., Wrathall, D. J., Sundsøy, P. R., Nadiruzzaman, M., Wetter, E., Iqbal, A., ... & Bengtsson, L. (2016). Unveiling hidden migration and mobility patterns in climate stressed regions: A longitudinal study of six million anonymous mobile phone users in Bangladesh. *Global Environmental Change*, *38*, 1-7.

Manyena, B., O'Brien, G., O'Keefe, P., & Rose, J. (2011). Disaster resilience: a bounce back or bounce forward ability?. *Local Environment: The International Journal of Justice and Sustainability*, *16*(5), 417-424.

Moumni, B., Frias-Martinez, V., & Frias-Martinez, E. (2013) Characterizing social response to urban earthquakes using cell-phone network data: the 2012 Oaxaca earthquake. In Proceedings of the 2013 ACM conference on Pervasive and ubiquitous computing adjunct publication, (pp. 1199-1208). ACM.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American journal of community psychology*, *41*(1-2), 127-150.

Pfefferbaum, B., Pfefferbaum, R. L., & Van Horn, R. L. (2015). Community resilience interventions: Participatory, assessment-based, action-oriented processes. *American Behavioral Scientist*, *59*(2), 238-253.

Song, X., Zhang, Q., Sekimoto, Y., & Shibasaki, R. (2014, August). Prediction of human emergency behavior and their mobility following large-scale disaster. In *Proceedings of the 20th ACM SIGKDD international conference on Knowledge discovery and data mining* (pp. 5-14). ACM.

TeleGeography (2016). Digicel Vanuatu Launches Country's First LTE Network. Retrieved from: https://www.telegeography.com/products/commsupdate/articles/2016/01/25/digicel-vanuatu-launches-countrys-first-lte-network/

The National Disaster Management Office of Republic of Vanuatu (2017, 4-26 May). Situation Reports. Retrieved from: https://ndmo.gov.vu/resources/downloads/com_jaextmanager/category/24-situation-reports

UN Global Pulse (2013, October) Mobile Network Data for Development. Retrieved from: http://www.unglobalpulse.org/sites/default/files/Mobile%20Data%20for%20Development%20Primer_Oct2013.pdf

UN Global Pulse (2018, April 24) Can Mobile Phone Traces Help Shed Light on the Spread of Zika in Colombia? Retrieved from: https://www.unglobalpulse.org/news/using_mobile_traces_curve_Zika_spread_Colombia

UN Global Pulse and GSMA (2017, June 29) The State of Mobile Data for Social Good Report. Retrieved from: https://www.unglobalpulse.org/news/state-mobile-data-social-good-report

UN Office for the Coordination of Humanitarian Affairs (2017, May 8). Asia and the Pacific: Weekly Regional Humanitarian Snapshot (2-8 May 2017). Retrieved from: https://reliefweb.int/report/vanuatu/asia-and-pacific-weekly-regional-humanitarian-snapshot-2-8-may-2017

Vanuatu Red Cross Society (2017, May 5). Information bulletin Vanuatu: Tropical cyclone Donna. Retrieved from: http://www.ifrc.org/docs/Appeals/17/IBVUCY050517.pdf

Wang, Q., & Taylor, J. E. (2014). Quantifying human mobility perturbation and resilience in Hurricane Sandy. *PLoS one*, *9*(11), e112608.

First In, Left Out : Current Technological Limitations from the Perspective of Fire Engine Companies

Katelynn A. Kapalo
University of Central Florida
katelynn.kapalo@ucf.edu

Pamela Wisniewski
University of Central Florida
pamwis@ucf.edu

Joseph J. LaViola Jr.
University of Central Florida
jjl@cs.ucf.edu

ABSTRACT

The cognitive demands and skills required of a fire engine company when assessing the scene of an incident and the systems they use to manage this information are a matter of life or death. We conducted a case study with an entire fire battalion in Florida (35 firefighters at varying levels of command) to assess their routine technology needs. Using a cognitive work analysis approach, we found that the firefighters in our study relied on mission critical systems that often failed, as well as disparate secondary systems that lacked integration. Capability gaps and inaccessible data also increased the likelihood of errors, creating frustration in the systems that both helped and hindered these firefighters in their daily job tasks. We describe what firefighters need from technology in its present state and we outline usability issues for technology designers and practitioners to leverage in the design of future systems.

Keywords

Fire service, case study, sociotechnical analysis, work analysis, information systems

INTRODUCTION

Every 23 seconds, a fire is reported in the United States (Haynes & Stein, 2017). From the time of the call, fire response teams must be on the move within 80 seconds for a fire call and 60 seconds for a medical emergency. This fast-paced response requires careful planning and coordination involving input from multiple sources, information from multiple devices, and communication from multiple people. With such a tight timeline for response, firefighters must be prepared to arrive on scene and successfully complete their mission, sometimes without accurate information or adequate time for pre-planning.

Despite a common need for accurate and real-time information, the fire service is very diverse in how it obtains, manages, and handles data due to variations in response areas and budgeting (Haynes & Stein, 2017). Consequently, firefighters may not have access to state-of-the-art equipment or facilities. For example, 15% of stations in the region we evaluated were over 40 years old according to the most recent National Fire Protection Association survey (NFPA, 2011). Additionally, aging equipment is also a concern. Recently, two firefighters in Massachusetts faced potentially fatal conditions after their radios failed to convey the "mayday" signals, indicating they needed aid in escaping the burning building (Firefighter Nation, 2017). These near-miss accidents require careful consideration of the system in which firefighters must operate, but more importantly warrant a closer look at the systems firefighters depend upon for conveying and obtaining information. Ideally aging equipment and outdated facilities would receive more attention, but the diversity in fire service conditions warrants a closer look to understand the holistic needs of each region and district.

Towards this end, our work focuses on better understanding the needs of 35 firefighters across the command structure from probational (newly trained) firefighters to fire chiefs with over 30 years of experience.

We conducted a case study in which the first author accompanied fire engine companies for an entire day to better understand the sociotechnical context surrounding the fire service. In this paper, we define *sociotechnical* as the interaction between the firefighters, the environment, and the systems/technology they use to operate in those environments. Our research was guided by the following questions:

- How does the sociotechnical system as a whole influence the behavior of the firefighters in our sample?
- More specifically, what are the main tools used by fire engine companies and rescue teams? Do these tools differ across ranks?
- How do these tools and technologies impact job tasks, job functions, and organizational values?

To better design technology to meet the needs of the fire service, we evaluated the broader sociotechnical system across all ranks of the fire service. To do this, we met with firefighters in six different stations (an entire battalion). We also interviewed three emergency operations center personnel responsible for sending information to first responders county wide, spanning over 40 fire stations. Drawing from the Cognitive Work Analysis framework as the theoretical a foundation for our research, we uncovered that the technology and systems used in our sample did not match the needs of the fire service (Vincente, 1999). Our key contributions include:

- An assessment of current systems and technology utilized by a fire battalion that services a large, metropolitan area in the Southeastern United States
- Translation of findings from cognitive systems methods into information that illustrates a richer understanding of the *sociotechnical environment* that firefighters work in
- Identification of areas where further investigation is required to create an effective system that can support firefighters across the command structure

RELATED WORK

Designing technology for emergency management and crisis response poses challenges due to the diverse number of stakeholders involved (Gomez & Turoff, 2007; Moynihan, 2009; Palen, 2007). The field of crisis informatics emerged from a need to better understand the perspectives of these stakeholders in a variety of disaster scenarios and emergencies by leveraging a multidisciplinary approach. Thus, this field has studied the implications of information dissemination across a variety of categories such as collaboration, community response, and information generation (Palen et al., 2007; Shklovski, 2008).

Efforts to better support first responders and emergency management personnel have largely developed from information sciences and decision-support tools. Research in this area has focused on ways to optimize tools and implement new systems at all phases along the system lifecycle. For example, previous work has focused on eliciting information requirements of first responders using a variety of approaches from sociology, grounded theory, and team performance research (Denef et al., 2009; Jul, 2007; Li et al., 2014; Prasanna et al., 2009; Toups & Kerne, 2007). The development of communication tools and systems has also been one of the defining research thrusts in this area (Dawkins et al., 2018; Groner et al., 2012; Jiang et al., 2004). Within the last year, research has assessed the attitudes of German fire departments on the acceptance of newly emerging technologies (Weidinger et al., 2018).

Due to the parallels between military operations and fireground command decision-making, the fireground was chosen as a domain to explore some of the most influential theories and models for decision-making in critical situations (Klein et al., 1989). More recent work in human factors has demonstrated the utility of focusing specifically on the fireground commander to better understand the barriers that impede successful mission management and ways to mitigate these through best practices (Gasaway, 2009). Similarly, work in HCI has focused on designing configurable systems that support the information requirements of four firefighter roles (Prasanna et al., 2013).

This paper directly addresses the role of technology for fire response in the United States. While we recognize that conducting a work domain analysis for firefighting is not novel, we provide a novel approach to the interpretation and presentation of key issues relevant to fire engine companies. We expand upon previous work

that identified some of the problems that incident commanders face by addressing the team across all ranks and updating it to be current with the advancement of technology (Dawkins et al., 2018; Jiang et al., 2004; Kapalo et al., 2018). The goal of our paper is to provide a *critical and current evaluation of the sociotechnical needs within current fire teams in the United States*.

We seek to summarize some of the important feedback to better inform the design of future technologies and to draw attention to the needs of firefighters, in our sample, who depend upon these systems in life or death situations.

METHOD

Participant Profiles

The participant sample consisted of n = 35 (32 male, 3 female) firefighters and n = 3 (3 male) emergency management personnel; n = 38 total. The fire service, while grounded in a para-military structure, has local and regional variations across the United States. All participants in this study are career firefighters and personnel. Although volunteer firefighting is prevalent in other parts of the United States, volunteer firefighting is uncommon in this particular area and state, since it is well populated. Participant quotes are denoted with their rank. Due to the possibility of potentially compromising participant anonymity, the term "chief" denotes any of the chief ranks such as battalion, district, assistant, or division. See Table 1 for an overview of ranks in the fire service.

Table 1. Firefighter ranks across the command structure

Rank	Role
Probational Firefighter	Newly Trained
Firefighter	Fire Suppression
Engineer	Driver/Operator of Equipment
Lieutenant	Crew Supervisor
Captain	Direct Operations
Battalion/District Chief	Highest Ranking Officer On-Duty
Assistant Chief	Operations
Division/Fire Chief	Operations/Administration

In this study, an engine company is composed of at least one firefighter, one lieutenant, and one engineer that all ride in the engine cab. The rescue team drives an ambulance separately and is generally composed of an emergency medical technician (EMT) and a paramedic. In this case, the firefighters all at least met basic EMT requirements, since it is common for firefighters to fill different roles depending upon their shift and response area needs.

Recruitment and Data Collection

The study occurred in two phases. Participants for the first portion of the study were recruited via email after Institutional Review Board approval was obtained. In the first phase of the study, the first author conducted focus groups with three Emergency Management Personnel and a group of five fire chiefs at the county Emergency Operations Center (EOC). This aligns with the recommended practice of conducting theoretical sampling in grounded theory-based research (Strauss & Corbin, 1994).

Following these two sessions, approval for a ride-along was granted to the first author through the fire rescue headquarters administration. The first author accompanied a battalion chief for five hours and a captain for five hours. Throughout this 10-hour ride-along, both the chief and captain were required to make stops at six different fire stations. The first author conducted eight additional ad-hoc focus groups throughout the duration of the study by obtaining verbal face-to-face consent from the firefighters at each fire station. The groups were formed based upon staff availability and interest. The first focus group was transcribed from an audio recording. Subsequent focus groups were not audio recorded due to the nature of incident response. All medical calls are subject to Health Insurance Portability and Accountability Act (HIPPA) regulations and patient privacy protections. Therefore, the first author took field notes for the remaining groups (2-10).

Table 2. Summary of data collection groups with participant counts and roles included

Study Number	Data Source	Participant Count	Group Constellation
1	Focus Group	3	Emergency Management Personnel
2	Focus Group	5	Assistant and Fire Chiefs
	RIDE ALONG (Conducted ad-hoc at fire stations & incident scenes)		
3	Interview/Observation	1	Battalion Chief
4	Interview/Observation	1	Captain
5	Focus Group/Observation	5	Fire Engine Company 1
6	Focus Group/Observation	4	Fire Engine Company 2
7	Focus Group/Observation	4	Fire Engine Company 3
8	Focus Group/Observation	6	Fire Engine Company 4
9	Focus Group/Observation	5	Fire Engine Company 5
10	Focus Group/Observation	4	Fire Engine Company 6

Data collection was informed by a cognitive work analysis approach (Rasmussen et al, 1990; Vincente, 1999). Cognitive work analysis developed from a need to understand the work of actors, the information behaviors surrounding the work, the environment in which work is performed, and the reasons behind the work performed (Fidel & Pjtersen, 2004). Our work employed this framework to guide the direction and scope of the studies conducted and the interactions with participants. A sampling of some of the questions asked during participant interactions mapped to major work analysis dimensions are captured in Table 3 below. Please note this is not an exhaustive list and meant to demonstrate how data was collected beyond observations on scene.

Data Analysis Approach

The first author coded all of the interview data. This coding process was completed by uploading all of the transcripts into MAXQDA 12. Two senior researchers reviewed samples of this coding to ensure agreement. The data was coded in three iterations, using the sociotechnical themes (people, technology, incidents) as an initial framework since these reflect the main tenants of the fire service work domain (Fidel & Pejtersen, 2004; Ramussen et al., 1990). These themes were chosen since they captured the broader dimensions of the cognitive work analysis framework: *environmental, organizational, social, activity, and individual*. However, because these dimensions are interdependent, the organizational, social, and individual dimensions were consolidated into a single code, categorized more broadly as *people*, since firefighting requires an understanding of how the command structure drives the social and organizational aspects of fire departments (Monynihan, 2009). As necessary, the interviewer performed sweeps to ask clarifying questions in order to capture information about a particular concept or term. Further sub-codes were added to better understand the three broad themes, leveraging the grounded theory approach (Goggins et al., 2013; Strauss & Corbin, 1994). Finally, a third coding iteration was used to check for accuracy and to ensure statements were categorized meaningfully and completely.

RESULTS

The structure of this section aligns with the themes emergent from our data and categorizes some of the end-user feedback we received to better understand the routine needs of firefighters in our sample. We first grouped these dimensions across three broad categories that comprise the sociotechnical environment of the fire department: people, incidents and technology. The revised coding structure, based upon the three code iterations, is captured in Table 4 below.

Table 4. Coding Structure

Sociotechnical Dimension	Sub-codes
People (Actors)	• Rank and expertise • Values • Expectations • Resource allocation
Incidents (Environment and Organizational)	• Operational constraints • Job tasks and activities • Responsibilities
Technology (Activities and Objects)	• Attitudes • Usability Concerns • Coping strategies • Constraints and failures

Table 3. Samples of Questions Scaffolding Data Collection Sessions

Framework Dimension	Sample Question(s)[1]
Analysis of User Characteristics	1. What information do you need to perform your job well? Can you provide me with some specific examples? Are you responsible for sending information to another teammate? a. What is their role? b. What kind of information is necessary for you to provide to them? 2. What kind of tools/equipment are available to you and which tools do you primarily rely upon? a. What information do these tools provide? If they do not provide information, what are their main purposes or functions? b. Are these tools located in the station, on the vehicle, where are they? c. How frequently do you use this set of tools during the day? Are there some that are rarely used?
Activity Analysis	3. From the time dispatch alerts you to the time you arrive on scene, walk me through an example call. What do you do first, and what information do you need to proceed and get to the scene? (may be real-life or a simulated training scenario) a. What are your goals in these scenarios and how do you plan your response? b. What do you prioritize first? ("size up") c. How do you know what to prioritize first? d. At a given moment, how many displays/devices are you obtaining information from? e. Can you explain to me in a few steps what that sequence of information gathering is like? Which device/interface do you look at first? f. Who are your teammates, and do they provide you with information? What does that sequence of information look like?
Organizational Analysis	4. Does your role change as situations change or do you generally perform certain tasks? Could you elaborate on this, if possible? Is it situation dependent or is it determined before your shift who will fill which role?
Work Domain Analysis	5. What are some actions that are taken to make sure a size-up is done correctly? Are you monitoring yourself or does leadership play a role in this? Who is in charge of making sure the team and plan adapt if the scenario changes? 6. In addition to your on-call responsibilities, what are some examples of other tasks you may be responsible for on-shift? (Administrative, maintenance, etc.)

[1] **Please note this is not an exhaustive list of all questions posed due to space constraints. Please contact the authors for the complete list of questions.**

People

Because our approach is grounded in understanding the dimensions of expertise and the self-organizing social structure driven by incident command, we sought to understand the unique roles across the fire engine company (LaPorte, 1996). We contend that within the company, there are prototypical roles each team member must fill, creating an opportunity to better understand the profile, values, and expectations of these team members. For example, the chief conceptualizes the engine company and arriving units as a sports team, with the incident commander acting as a coach. This organization structure provides further insight on how responsibilities are distributed and shared. It also provides context surrounding values and expectations more broadly:

> *"The IC [incident commander] is like a football coach who is calling the plays, absorbing the whole scene, delivering out the task in a priority fashion, their information is more global: where are all my units, what are the changing conditions, what are the needs that I have to address, what are the resources I have, and how do I get the resources I need?"- Chief*

Rank and Expertise

The above statement provides some insight into the challenges the incident commander faces regarding the amount of information they are required to process. In contrast, the crew on the engine has different priorities. They were likened to athletes carrying out plays, and take more of an offensive approach:

> *"I care about what is in front of me, what is overhead, what is in the room, I'm listening to what's around me."- Firefighter*

Despite these conceptualizations, there are some nuances in understanding the rank (social) structure on the fireground. One chief succinctly explained that there are multiple types of supervisors on the fireground to ensure that incidents move swiftly and quickly, but that those roles require different things from technology and tools. He stated:

> *"There are two types of supervisors in incident command: The first is somebody who is commanding a crew and navigating in the truck with them, a lieutenant. The second is somebody [like a battalion chief or captain] who generally is alone and arrives as an individual unit. So, they are navigating, orienting, and planning by themselves."-Chief*

Thus, the role of the battalion chief can be potentially more demanding due to the added requirements of navigating to an incident scene alone, while operating the vehicle, listening to the radio, and monitoring the MDC for changes in incoming information. They may also be required to access documents such as pre-incident plans. This details a richer understanding beyond that of the "prototypical" user in the sense that chiefs and company officers have different priorities than the engine crew when responding on scene. When considering the technical system and incident scene, it is clear that officers have different information needs.

Job Expectations and Resource Allocation

Expectations are emphasized as important, each member has a role to fill and as the incident progresses, it may become necessary for others to join the team. As a consequence, *flexibility and accountability* were two concepts that were consistently referenced in participant responses.

> *"The expectation for the IC [incident commander] is that he/she prioritizes accountability. They need to know where everyone is and what they are doing at the scene from start to finish." –Chief*

In addition to accountability, team members also explained how they coordinate tasks, sometimes with an implicit level of *trust*. For example, one engineer explained how he makes decisions regarding the appropriate amount of water flow. He recognized that this sort of behavior bounds the system, but not explicitly. Instead, he uses his judgement and understanding of his teammate's job tasks to fulfill the requirements of getting the water on the fire in a timely manner.

> *"There's an understanding there. I know that if I put out the maximum pressure required on the line [hose] it's going to knock the guy at the end of the line around and that would piss him off and slow us down. So, I use my judgment, it's not always by the book."- Engineer*

These values of *accountability and flexibility* were prevalent across all interviews but were typically emphasized at the higher levels of command, where the ranks become more supervisory and thus, more critical in terms of ensuring the team's safety.

Incidents

Generally, an "incident" is defined as an instance of a particular activity in which observations can be made and there are directly measurable consequences based upon the actions taken (Flanagan, 1954). In the fire service domain, an incident is any sort of call in which emergency medicine or fire suppression activities are involved. Although incidents vary in nature, in this paper we consider all incidents to be emergencies requiring a time constrained response that involved *protocols and action* among individuals belonging to the engine company. According to our sociotechnical approach, the incident represents the operational environment in which people are present and technical systems are utilized.

From our study observations and interactions with participants, we noted that the most prevalent themes surrounding incident response involved being *adaptable* to rapidly changing scenarios and the ability to think forward and plan ahead, regardless of role or incident. All firefighters had to be prepared to encounter situations that are time-sensitive and require methodical preparation. Across all of the themes in the incident category all participants emphasized the ability to adapt to the incident as one of the main values in this fire department.

Operational Constraints

Participants made frequent references to "playbooks," "thinking ahead," and time constraints. This theme of adaptability stems from a need to embrace the dynamic details of the situation in order to successfully complete the mission.

> *"There's not just one playbook, once one plan is null, we move to a back-up plan, and then we have another back-up plan if that one fails."-Lieutenant*

> *"I'm always thinking half an hour ahead."-Chief*

> *"As an incident commander I am already thinking about where the hydrants are, where to stage, how much room we need to leave, whether we have a decent water supply, where the trucks are going to go, all of this decision-making has to happen quickly."-Captain*

An emergency management center employee captured this requirement well in the following statement:

> *"Essentially there are three levels of response—task, tactical, and strategic. Our responders are filling different roles during the course of an incident; however, these levels determine the scope and perspective of each role." -Emergency Manager*

Despite this need for quick decisions, our study revealed that the systems firefighters rely upon do not necessarily meet their needs, and in some cases can constrain incident response. We describe this idea in more detail below.

Specific Job Tasks, Activities, and Constraints

Incident response is dictated by decision-making of commanders as well as team coordination, but it is also dependent upon other factors outside the control of the firefighters. For example, a demanding and challenging situation arises when a water supply is not readily available. The tanker shuttle is a strategy and protocol implemented when water sources are scarce or not accessible. In one instance, a recently developed community in the area did not contain enough fire hydrants to supply the hoses for a house fire. For this reason, a tanker shuttle is established to provide support for the water supply. However, the logistics of this protocol can be daunting. There is often not enough water on one tanker truck, so portable tanks and a system for replenishing this water needs to be established. Typically, one captain or senior officer is in charge of managing this process while the other serves as incident commander of the entire scene.

> *"One major concern with recently developed communities is the lack of fire hydrants. They are typically expensive, and some developers complete the bare minimum for coding and zoning. As a consequence, the logistics of putting out a routine house fire may be compromised by lack of water and you have to move to plan B." –Engineer*

Technology and Equipment

To support incident response, firefighters need information about the emergency at hand. Firefighters rely on technical systems to understand and react to the dynamic nature of incidents. Often this information is incomplete and lacks detail. Therefore, technology can convey what little information is known.

The Mobile Data Computer (MDC) represents a central component in the system as it facilitates the two-way exchange of information between the Computer Aided Dispatch (CAD) system, the system that transmits emergency information from dispatch, and the firefighters on duty (see Figure 1 and Table 5). While the MDC is equipped with navigational capabilities, these capabilities are augmented by separate devices, such as a Garmin (GPS). Because of this central role, we elaborate on this device further to explain its implications in later sections of this paper. The MDC represents the hub for information in which firefighters of all ranks access incident data, create reports, and log information. Despite its theoretical utility, in practice it is often the source of frustration and error due to connectivity issues, usability problems, and general lack of functionality. These themes were introduced by participants in the quotes below:

You have 45 seconds to understand information from several disparate systems, you are flipping screens, switching back and forth from the mapping screen and the incident screen..."-Lieutenant

"The MDC printout has more information than someone can read in 30 seconds..."-Firefighter

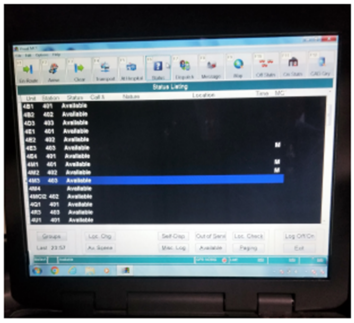


Figure 1. Example of a Mobile Data Computer (MDC) or Mobile Data Terminal (MDT) used by fire engine companies.

In addition to the MDC, firefighters rely upon several different technologies in their routine job tasks. Some of these technologies are listed in the table below. Please note that due to local variations, some technologies such as automated dispatch systems and tablets may exist in other departments. Additionally, there is other equipment stored on the fire engine that may be considered a major tool or technology (e.g. hydraulic tools). However, the goal of this table is to summarize the core technologies routinely used by engine companies.

Table 5. Summary of Core Technologies Used by Firefighters Daily

Device	Usage/Purpose	Users
Mobile Data Computer (MDC)	Information, Logs, Reports	All
Global Positioning System (GPS)	Navigation	All
Paper Map book	Navigation	All
Radio	Communication	All (In-Vehicle)
Camera	Crew Surveillance/Monitoring	All (In-Vehicle)
Mobile Phone	Communication	Officers
Portable Radio	Communication	All
Thermal Imaging Camera (TIC)	Mission Tasks	Lieutenant/Team
Self-Contained Breathing Apparatus (SCBA/" Air Pack")	Mission Tasks/Protective gear	Mission Team
SCBA Tracker	Mission Tasks/Monitoring	Incident Commander

Attitudes Toward Technology

Contrary to the need for flexibility that we noted from both the dynamic nature of incident response and the changes in staffing that may occur, we noticed that participants did not express that current technology reflected these values. Instead, much of the participant frustration stemmed from the inability to use technology that was flexible and mobile to fit with the dynamics of incident response.

> *"Usually we are given a system and it's not perfect. We make the best of it. We have to use it even when it slows us down."-Firefighter*

Some participants felt that these technologies were not appropriately tailored for their job tasks as exemplified below:

> *"Much of the technology we have was created for the S.O. [Sheriff's Office]. They just put a firetruck icon on it and hand it to us. There's not really much consideration about what we do."-Firefighter*

Generally, attitudes toward technology indicated ambiguity surrounding needs. On one hand, firefighters across all ranks expressed that technology was necessary to carry out their job tasks. However, some company officers indicated annoyance and irritation with new systems since they were often unreliable. Although there are electronic rosters, one chief felt that the traditional methods were more reliable since there was less of an opportunity for error:

> *"I prefer to stick with the things that work. My whiteboard with all the staffing details does not fail."-Chief*

Additionally, new technologies such as the automated dispatch system tended to fall short of expectations due to flaws with the system, causing negative perceptions of some of the newly integrated technologies.

> *"The automated voice that provides dispatch information is irritating at times. She often mispronounces things like the abbreviation for "drive" as "doctor." -Captain*

Usability Concerns: Data Inaccessibility and Capability Gaps

A majority of the devices the firefighters used in this sample were not entirely mobile or portable, see Table 5 above. The MDC is not actually completely mobile; it is typically mounted in the vehicle. Therefore, it presents issues with regard to functionality. For example, one Lieutenant commented:

> *"A command tab exists on the MDC for planning. But since the MDC is not portable, no one uses it. It would also require maintenance of another module." - Lieutenant*

A seemingly useful opportunity for planning or visualizing information is missed when a tool is not functional in the environment for which it will be used in. This command tab is not useful if the computer cannot be removed from the truck or if the MDC loses connectivity since new information cannot be added into the system.

Some of the participants on shift expressed that their needs were not currently met due to lack of features related to current technology. It was apparent that the radio was a source of frustration, but also a necessary form of communication. The lack of multiple input capabilities made it challenging since only one person at a time can "talk" on the radio. The quote below indicates that firefighters sometimes struggle with this bottleneck in communications.

> *"It's like talking through a straw [on the radio], one at a time, that makes it impossible."-Firefighter*

To illustrate another example, the officers on scene indicated a need for higher level information. Chiefs and captains expressed a desire for streamlined information that could be quickly visualized.

> *"Something that gives an overhead view would be important, but it does not exist. I can pull an overhead view on Google maps, but it's usually a picture from two years ago..."-Chief*

> *"Give me a report, I can send more stuff that way if it sounds like that is where the threat is, I need this kind of [summarized] information..."-Captain*

"It would be beneficial to have a quick picture and summary for size-up. If there was a way to summarize this information, more people would use it. It's also an issue of accessibility. I have to pull up a separate network just to access these plans. You don't have that kind of time to spend 15 minutes trying to get to a plan."-Captain

It was apparent from the field study observations that firefighting involves tasks that require heavy reliance on visual information. This includes line of sight information, as well as signaling and artifacts that manage the number of people on scene, air pack utilization, etc. Despite this, much of the technology used in firefighting does not present information in a way that easily consumed visually. For example, the MDC presents information in paragraph form and radio communications are exclusively auditory. Of the technologies that do present information visually, they are often cumbersome and difficult to use. Most notably, the MDC map only shows directions from a northward orientation. This means that when navigating, the firefighters must translate all the directions from north to get to the scene. This is a poor allocation of resources and visual attention because there is technology readily available to mitigate this capability gap. As one participant captured, there are too many interfaces for the incident commander to allocate attention to:

"You really need someone like a scribe or assistant to monitor the pack tracker (Self Contained Breathing Apparatus, SCBA) interface" –Engineer

Additionally, some participants identified capability gaps related to a lack of visual information. For example, dispatch can describe a picture of a motor vehicle accident scene taken through a red light camera to the incident commander over radio, but currently, in this department, there is no capability to send the picture to any arriving units or line officers directly.

"[For traffic accidents] Dispatch has control of the red-light cameras but they cannot send us the picture. So, they have to describe what they see. It would be nice if we could see the accident scene before we get there." –Chief

This also affected the ability for officers to plan strategies and prioritize tactics since information could not be easily accessed via the MDC interface.

System Failures and Coping Strategies

All (35) of the fire team participants reported at least one technology/device failure that is routine and occurs daily. Of these reports, the majority cited the MDC is as the piece of equipment most likely to fail. From observations, one call was missed by leadership due to lack of signal in the fire station. Additionally, the MDC experienced connectivity issues the entire shift. Judging by the more experienced leadership's reactions, it was completely normal for these failures to occur. Many firefighters expressed frustration with the failing tools and recently implemented technology. The more experienced leaders found methods of their own for coping with repeated issues.

"I have to keep a separate flash drive with information about local schools on them. Relying on technology that typically fails [the MDC] is not a good plan." -Chief

System failure emerged as one of the most frequent and rich codes in our analysis. Relying on errant technology creates a frustrating and stressful user experience. Using outdated technology or equipment that continuously fails does not support their mission and increases opportunities for error. We noticed this theme to be prevalent due to the disjointed systems that the entire fire battalion uses.

"When I can pull the information up, it is nice, but that is rare." -Chief

In addition to the implications for incident response (slower response times, less accurate coordination), these points of failure seemed to suggest that the firefighters in our sample believed their job functions came as an afterthought rather than a priority.

"For mass casualties/large scale incidents with 5 or more people wounded, it [the MDC] will usually provide you with a list of available hospitals. This feature [hospital suggestion] is sometimes down which complicates situations. Now I have to radio all the hospitals."-Chief

Several team members came to accept that sometimes failure was inevitable, and they needed to rely on other means for getting updated information, such as the radio.

"No way to know when system connectivity is lost because the MDC does not alert you."- Chief

This is also apparent when the radio and MDC provided conflicting information. For example, there was one instance during the observation shift in which the chief was canceled on the call. The MDC connectivity was lost, so the computer did not update this information. When you are operating a vehicle at sixty miles per hour and also listening to the radio and reading the MDC, this poses significant risks for not only the officer operating the vehicle, but also for the civilians on the road. Consequently, technology has the potential to compromise scene safety.

DISCUSSION

Emergent themes surrounding the lack of cohesion with the technical system provided support for the idea that both the *social* and *operational* environment place demands on the *technical systems*, which are not sufficient in their current state. We noted that the technical system comprised of disparate systems that evoked feelings irritation or annoyance, negatively impacting user perception. This theme was pervasive across all ranks, but more so at the higher-ranking end of the command structure. We interpret this as an artifact from expertise, since captains and chiefs typically have years of experience and have witnessed the changing dynamics of emergency management technology over a large period of time.

Based upon our findings, our contributions are two-fold. First, we contend that identification of existing problems can lead us to better understand the needs of firefighters *independent* of current systems, which is important for understanding how to create new technologies that support the work domain of firefighting. Second, we contend that a richer understanding of the sociotechnical structure surrounding the fire department's operations allows us to better address the *gaps and deficiencies* identified in this paper:

People (Individual & Social)

Upon analysis, our data is aligned with the idea that multiple users have different needs from the MDC. In its current state, the MDCs in this department were not sufficient for incident command and often frustrated the engine companies who were attempting to perform simple tasks such as navigation or pulling up planning information. The use of GIS-based systems has been suggested as a lower-cost solution for displaying information to crews and increasing interoperability (Abdalla et al., 2007). However, we recognize each department will have different needs.

Additionally, one of the major findings of this study indicated that back-up systems typically did not involve technology and were sometimes preferred over the use of current systems, depending upon user attitudes and values. One of the ways to mitigate negative attitudes toward these technologies is to consistently gather user input and provide ways to leverage existing, reliable, and lower-cost technologies that can be adapted for the fire service. For example, replacing MDCs with tablets, or augmenting MDCs with tablets, is an easier way to increase functionality. Small solutions such as implementing tablets or changing the mobility of the MDC could have a positive impact on user experience, enhancing productivity and safety. However, due to the complex nature of funding, such changes are not easily implemented. This is particularly true when a department is navigating several risks at once, they must choose between updating MDCs or purchasing a second set of turnout gear to reduce risk of carcinogen exposure. Additionally, environmental factors such as increasing resources, connectivity, and interoperability could increase trust in these technologies, thus aligning user values to match the system and reducing frustration or error. We elaborate on these points below.

Environmental

Incident response requires the ability to quickly adapt to changing conditions. Additionally, now more than ever before, firefighters are dealing with what are known as potentially violent situations (PVS). As a consequence, protocol now requires firefighters to wear protective gear on scene and stage where necessary. This fundamentally impacts operating procedures since scene safety must be conceptualized differently and prioritized in a way that has not been previously addressed. More importantly, the current technologies used by the fire engine companies created tension due to the conflicting information needs and the multiple functions the MDC must fill. Not only must it update with current information, but static information, such as planning or inspection data, also needs to be accessible on scene. Increasing connectivity and providing further resources such as unmanned aerial vehicles and other emerging technologies could enhance user experience and support firefighters operating in complex and dangerous situations. The use of dedicated broadband networks and

increased connectivity could facilitate more reliable technology. Finally, we elaborate on this at the organizational level as well, since firefighters are dealing with increasingly different and dynamic incidents.

Organizational & Activity

Although there have been strides made in understanding firefighter communication and coordination across the team, relatively few papers have exposed the research-practice gap that exists in a majority of the United States. That is, although we are designing and evaluating emerging technologies for use in the fire service, the majority of departments are severely understaffed with limited budgets. Although the necessary capabilities may exist, little work directly acknowledges the fact that most departments are not even operating with current technologies available.

For example, the department we evaluated consistently cited cost and budget as one of the limiting factors preventing the use of certain functions on the MDC and the use of upgraded technologies. Once a software product is purchased, much of the budget is spent on maintenance, rather than increased functionality. As a result, this department suffers from a lack of interoperability and is challenged with making the best of the resources available to them. In addition to technology, we also found that staffing/administration, time, response area type, and budget all play a role in the adoption and maintenance of technological systems. Perhaps one of the more interesting findings has to do with the way modern dispatch systems and technologies were developed from the needs of law enforcement (Brenner & Cadoff, 1985). This is still a current issue and these technologies are often later transitioned by manufacturers and implemented in fire departments without much consideration for fire-rescue teams who ultimately serve a different function than law enforcement. One common pattern that emerged in our research was the reiteration that fire response and law enforcement have two separate job functionalities. Despite this, there has been a movement to increase interoperability between law and fire in the form of rescue teams (Marino et al., 2015). As a consequence, these changes require reevaluation of current systems, to accommodate the changing interagency and multiagency response needs.

There are several limitations of this study that impact the generalizable content of our results. First, we did not survey multiple fire departments across the United States. While we recognize that this does not necessarily mean our work generalizes to all U.S. fire departments, we can say that our study supports prior work and seems to be aligned with most common practices in major fire departments (Dawkins et al., 2018; Jiang et al., 2004). Additionally, we were able to assess two different agencies within the same region, which enhanced the findings. However, it should be noted that in more rural parts of the country, volunteer firefighters are more prevalent. This poses safety and training challenges beyond the scope of this paper. Further research must be conducted to determine how the needs of volunteer fire departments can be addressed. We plan to leverage this data to inform the design process for both hardware and software prototypes in the next iteration of our study. By focusing on all ranks in the command structure, this work has directly pointed out where HCI practitioners, designers, and researchers can focus further investigations to enhance the user experience of firefighters across all ranks using the same systems.

CONCLUSION

In our study, we found that the technology firefighters depend upon is not reliable or configurable in its present state. The results of our work suggest that the dynamic and frequently changing operational environment needs to be reflected in the systems firefighters use to better support them in their day-to-day tasks. Furthermore, we noted the perceived needs of the firefighters across all ranks did not necessarily match the current systems they depend on. We contend that by using a cognitive systems driven approach that themes emergent from observations and qualitative data collection provide valuable insight. The goal of this work is to leverage this data set as a foundation for further research in building more resilient and adaptive systems for first responders.

ACKNOWLEDGMENTS

We would like to thank the anonymous firefighters and emergency managers who participated in this research. The authors would particularly like to thank Ari Schein, Billy Richardson, and Ken Henderson for their support. This paper is dedicated to the memory of Ron Plummer, John Perez, and Stephen "Shakey" Vanravenswaay. Any opinions in this paper are those of the participants and authors alone and do not represent the official views of the US government, any federal agency, or fire department.

REFERENCES

Abdalla, R., Tao, C. V., & Li, J. (2007). Challenges for the application of GIS interoperability in emergency management. In *Geomatics Solutions for Disaster Management* (pp. 389-405). Springer, Berlin, Heidelberg.

Brenner, D. J., & Cadoff, M. A. (1985). *Guide to Computer-Aided Dispatch Systems*. US Department of Commerce, National Bureau of Standards.

Denef, S., Ramirez, L., & Dyrks, T. (2009, April). Letting tools talk: interactive technology for firefighting. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems* (pp. 4447-4452). ACM.

Fidel, R., & Pejtersen, A. M. (2004). From information behaviour research to the design of information systems: The Cognitive Work Analysis framework. *Information Research: an international electronic journal*, *10*(1), n1.

Firefighter Nation (2017). Radio Problems and Mayday at Massachusetts Fire. Accessed from: http://www.firefighternation.com/articles/2017/05/ radio-problems-and-mayday-at-massachusetts-fire.html

Flanagan, J. C. (1954). The critical incident technique. *Psychological bulletin*, *51*(4), 327.

Gasaway, R. B. (2009). *Fireground Command Decision Making: Understanding the Barriers Challenging Command Situation Awareness*. Lulu. com.

Goggins, S. P., Mascaro, C., & Valetto, G. (2013). Group informatics: A methodological approach and ontology for sociotechnical group research. *Journal of the American Society for Information Science and Technology*, *64*(3), 516-539.

Gomez, E. A., & Turoff, M. (2007, January). Community crisis response teams: Leveraging local resources through ICT e-readiness. In *40th Annual Hawaii International Conference on System Sciences, 2007. HICSS 2007.* (pp. 24-24). IEEE.

Groner, N., Jennings, C., & Robinson, A. (2012, March). A negotiated-text method for assessing situation awareness information requirements from emergency responders. In *Cognitive Methods in Situation Awareness and Decision Support (CogSIMA), 2012 IEEE International Multi-Disciplinary Conference on* (pp. 259-263). IEEE.

Haynes, H. J., & Stein, G. P. (2017). *US Fire Department Profile 2015*. Quincy, MA: National Fire Protection Association.

Jiang, X., Hong, J. I., Takayama, L. A., & Landay, J. A. (2004, April). Ubiquitous computing for firefighters: Field studies and prototypes of large displays for incident command. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 679-686). ACM.

Jul, S. (2007, May). Who's really on first? A domain-level user, task and context analysis for response technology. In *Proceedings of the 4th International Conference on Information Systems for Crisis Response and Management ISCRAM 2007* (pp. 139-148).

Kapalo, K. A., Bockelman, P., & LaViola Jr, J. J. (2018, September). "Sizing Up" Emerging Technology for Firefighting: Augmented Reality for Incident Assessment. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 62, No. 1, pp. 1464-1468). Sage CA: Los Angeles, CA: SAGE Publications.

Klein, G. A., Calderwood, R., & Clinton-Cirocco, A. (1986, September). Rapid decision making on the fire ground. In *Proceedings of the Human Factors Society Annual Meeting* (Vol. 30, No. 6, pp. 576-580). Sage CA: Los Angeles, CA: Sage Publications.

La Porte, T. R. (1996). High reliability organizations: Unlikely, demanding and at risk. *Journal of contingencies and crisis management*, *4*(2), 60-71.

Li, N., Yang, Z., Ghahramani, A., Becerik-Gerber, B., & Soibelman, L. (2014). Situational awareness for supporting building fire emergency response: Information needs, information sources, and implementation requirements. *Fire Safety Journal*, *63*, 17-28.

Marino, M., Delaney, J., Atwater, P., & Smith, R. (2015). To save lives and property: high threat response. *Homeland Security Affairs*, *11*, 1-17.

Moynihan, D. P. (2009). The network governance of crisis response: Case studies of incident command systems. *Journal of Public Administration Research and Theory*, *19*(4), 895-915.

National Fire Protection Association (2011). Third Needs Assessment of the U.S. Fire Service Florida. http://www.nfpa.org/news-and-research/fire-statistics-and-reports/fire-statistics/the-fire-service/administration/needs-assessment

Palen, L., Vieweg, S., Sutton, J., Liu, S. B., & Hughes, A. (2007, October). Crisis informatics: Studying crisis in a networked world. In *Third International Conference on e-Social Science* (pp. 7-9).

Prasanna, R., Yang, L., & King, M. (2009, May). GDIA: A cognitive task analysis protocol to capture the information requirements of emergency first responders. In *Proceedings of the 6th International ISCRAM Conference* (pp. 10-13).

Prasanna, R., Yang, L., & King, M. (2013). Guidance for developing human–computer interfaces for supporting fire emergency response. *Risk Management*, *15*(3), 155-179.

Rasmussen, J., Pejtersen, A. M., & Schmidt, K. (1990). *Taxonomy for cognitive work analysis*. Roskilde, Denmark: Risø National Laboratory.

Shklovski, I., Palen, L., & Sutton, J. (2008, November). Finding community through information and communication technology in disaster response. In *Proceedings of the 2008 ACM conference on Computer Supported Cooperative Work* (pp. 127-136). ACM.

Strauss, A., & Corbin, J. (1994). Grounded theory methodology. *Handbook of Qualitative Research*, *17*, 273-85.

Toups, Z. O., & Kerne, A. (2007, April). Implicit coordination in firefighting practice: design implications for teaching fire emergency responders. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 707-716). ACM.

Vicente, K. J. (1999). *Cognitive work analysis: Toward safe, productive, and healthy computer-based work*. CRC Press.

Weidinger, J., Schlauderer, S., & Overhage, S. (2018). Is the Frontier Shifting into the Right Direction? A Qualitative Analysis of Acceptance Factors for Novel Firefighter Information Technologies. *Information Systems Frontiers*, *20*(4), 669-692.

Design and development methods for improving acceptance of IT among emergency responders

Erion Elmasllari
User-Centered Ubiquitous Computing
Fraunhofer FIT
Schloss Birlinghoven
53754 Sankt Augustin, Germany
erion@elmasllari.com

ABSTRACT

Various sources report a low adoption of IT-based tools in emergency response, as well as a negative attitude of responders to such tools. The responders' needs, simply put, are not met by the IT-based tools offered to them. Observing this situation through a user-centered design lens, we note that such problems typically stem from insufficient or erroneous context analysis. The deficiencies become even more pronounced when considering that emergency response represents a complex, adaptive socio-technical system. We also note that the appropriate methodology for designing ER systems is rarely discussed in literature and in research papers. To fill that void, the present paper discusses a minimal set of techniques that, both in our experience and according to state of the art practice, can guide developers towards positively-accepted IT systems for emergency response.

Keywords

Acceptance of ICT, Methodology, User Centered Design, Complex Socio-technical Systems, Requirements Engineering, Emergency Response

PROBLEM STATEMENT AND INTENDED AUDIENCE

The allure of using IT in emergency response has long been recognized by both researchers and practitioners. (Turoff et al. 2004; Ganz et al. 2013; Adler et al. 2011; Elmasllari 2018a) propose complete frameworks for emergency-related IT systems, whereas (Elmasllari and Reiners 2017) report 111 articles on electronic triage alone. Paradoxically, even though both "supply" and "demand" for IT in emergency response are high, the actual adoption of IT-based tools is very low and the attitude of responders to them is negative (Paul et al. 2008; Orthner et al. 2005; Adler et al. 2012; Ammenwerth et al. 2006; Elmasllari and Reiners 2017). (Elmasllari 2018b) has identified 12 problematic areas at the root of this attitude, whereas (Schmitt et al. 2007; Wu 2009; Jennings et al. 2017) note several hindrances due to the technology itself. The increasing discrepancy between what is offered and what emergency responders need was also a pressing topic in the previous ISCRAM conference (Tapia 2018).

From a software engineering perspective, the current situation represents a discrepancy between what users need and what IT systems implement. This problem, stemming from missing or wrong requirements, is a classic in the IT industry (see figure 1). It arises from the use of inappropriate or insufficient methods to elicit and understand user needs in the first place. Already in 1993, (SW Thames 1993) identified the correct methodology as crucial for the success of emergency response systems. Five of the six acceptance dimensions and 8 of the 12 problem areas for acceptance of IT identified by (Elmasllari 2018b; Elmasllari and Reiners 2017) can be completely avoided by using the correct analysis and development methods.

Given the above, there is a clear need to educate system designers about good methods for eliciting user needs in emergency response. Such knowledge, however, is not freely published by commercial suppliers, who prefer to keep their methods secret, nor by academic researchers of ER systems, who include very little details about

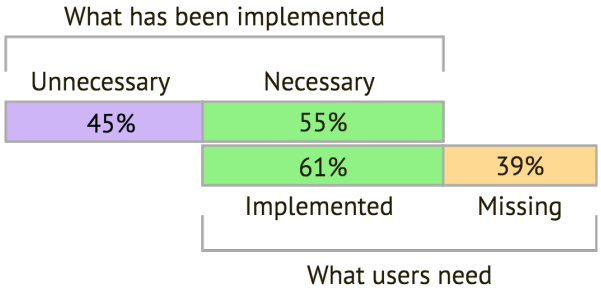


Figure 1. The mismatch between user needs and IT system implementation. Source: (The Standish Group 1995; Fowler 2002)

methodology in their papers – just enough to describe the study. To fill the void, the present paper is dedicated to educating system designers about good methodologies. We do not aim to produce a tutorial on the methods we list, but we do aim to discuss a minimal set of techniques that, both in our experience and according to state of the art practice, can guide designers and developers of ER systems towards positively-accepted products. We also provide recommended readings to further the proficiency in the details of each technique.

This paper is based on our decade-long, hands-on experience developing various complex socio-technical systems related to emergency response, security in large events, work in dangerous factory environments, sterilization of surgery tools, etc. The methods we propose were all successfully used in the research and development of 10 different IT-based systems in all areas of emergency response as part of the EU FP7 BRIDGE project. By the end of development all systems passed rigorous tests by real users in real conditions; at least four systems became commercially available, while the rest had reached TRL7/8.

FUNDAMENTAL CONSIDERATIONS ON EMERGENCY RESPONSE SYSTEMS

To better understand the problem, a short discussion on complex systems is necessary. (Simon 1962) defines "complex systems" as "made up of a large number of parts that interact in a non simple way", and where "system properties and behavior are hard to infer based on the properties of the parts". Complex *socio-technical* systems (CSTs) are complex systems where some of the components are humans or organisations, i.e. the social and technical aspects are equally important. Finally, complex *adaptive* systems are complex systems that adapt and organize themselves without being deliberately managed or controlled (Holland 1995).

Complex systems are not merely "big and complicated". They have particular characteristics and behaviors that make them very particular:

1. The properties and behavior of a complex system are hard to infer, even when the properties and behavior of each part or component are well-known (Simon 1962).
2. Complex systems cannot be studied or designed using a reductionist approach, such as decomposing the system top-down in parts and studying or designing each part separately.
3. The behavior of a complex system is nonlinear: tiny changes can lead to large differences in the outcome (Waldrop 1993).
4. CSTs have very tight coupling between people and technology, especially in regard to social, communication, and interaction aspects.
5. CSTs emerge over time and organize themselves without being under the full control of any singular entity (Holland 1995).
6. Complex adaptive systems are intrinsically resilient and will try to sustain their operation under all conditions (Hollnagel 2013).

When considering the emergency response effort as a complete "system of response", it can be shown that ER is a complex socio-technical system with a very strong adaptive element (Elmasllari 2018a). The traditional software engineering approach – split the problem top-down into parts, solve the parts, then combine the solutions – clashes directly against point 2 above. As a result, traditionally-developed solutions either do not match users' needs and

get rejected, or they exhibit unexpected and emergent behaviour, undermining both the capability of the engineer to understand the system and the trust of the users on the system.

Characteristic 6 above, resiliency, implies that complex adaptive systems will protect themselves by resisting *external* efforts to change the system. This means that efforts to *impose* a new tool or technology in ER will be met with resistance and rejection. The best illustration of this is the failed introduction of the dispatch tool for the London Ambulance Service, which was sabotaged by users (SW Thames 1993; Shapiro 2005). The implication is that successful, well-accepted IT tools for ER must arise from within the ER system, i.e. must be developed by the responders themselves.

One objection to our view of emergency response as a single system is that, in practice, commercial suppliers focus only on aspects of ER, such as "logistics management", "communications", etc. This objection misses the point. It does not matter that the supplier addresses only a tiny part of the response. What matters is the view from the responders' side. The responders' context is the *complete* response, which is a complex system. To gain trust and acceptance, any IT solution deployed in this context has to take the complexity characteristics into account.

A second objection is that "there is a difference between a methodology to develop one specific functionality (e.g. detect a crisis location from tweets) and a methodology to develop a tool for use in emergency response". Strictly speaking this is true, but as soon as the specific functionality is used in a complex context, the argument reduces to the previous objection and is similarly rejected.

The correct way to design IT systems for emergency response was outlined already by (SW Thames 1993; Shapiro 2005), who recommended that, when designing emergency systems in the future:

- The emergency response context and users need to be studied very carefully.
- Emergency professionals' trust in the system needs to be earned, otherwise they will distrust and sabotage systems imposed on them.
- Emergency-related IT systems must be designed with constant and wide participation from the users.

Seeing that acceptance of IT in emergency response has changed little in the last 25 years, the aim of this paper is to extend those recommendations and show concrete methods how to study the ER context, how to involve users, and how to design systems that easily gain the responders' trust for successful adoption in the ER practice.

HIGH-LEVEL APPROACHES AND PARADIGMS

Only two commonly-used development paradigms match the recommendations from (SW Thames 1993). We present these paradigms shortly below; an in-depth view is provided by (Norman and Draper 1986; Ritter et al. 2014; Ehn 2008; Shapiro 2005).

User Centered Design

User Centered Design (UCD) is a design and development paradigm that puts the end-user at the center of the "design universe" (Norman and Draper 1986; Norman 1988). The UCD paradigm first analyses the context: capabilities, characteristics, and goals of the user, as well as the environment within which the system is to work (see Figure 2). This analysis is then expressed as requirements and further, in step 3, is implemented in a prototype to be tested with actual users in real conditions. The test insights are used in a new iteration, deepening the understanding of the context, clarifying the requirements, and making better prototypes until all user needs and expectations are fulfilled and the system can be successfully used in the intended environment.

UCD does not draw a distinction between the technological part and the social part of the system, but considers both of them holistically (Ritter et al. 2014). With UCD, the development effort cannot stray too far from users' needs; the resulting systems tend to match the users' workflow, capabilities, and needs extremely well. These qualities make UCD appropriate for the complex, critical, and change-sensitive systems related to emergency response.

UCD also has some drawbacks, but these can be easily avoided by Participatory Design (details in the next section):

- UCD was meant for human-machine interaction, but the dominant interaction today is human-human, mediated by machines.
- When the user is at the "center of the design universe", she is unaware of how the system itself interacts with the world (Slavin 2016).
- Users do not live isolated from other technology, nor do they keep a coherent set of beliefs and preferences (Visciola 2003). A pure-UCD development can waste time catching-up with shifting preferences.

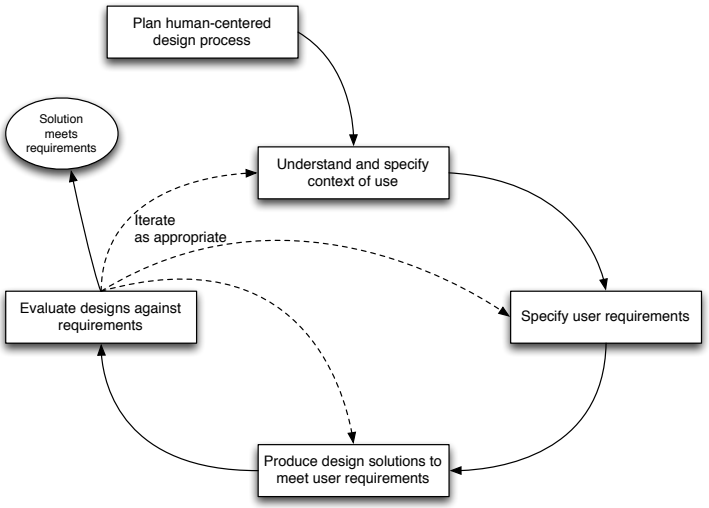


Figure 2. The ISO 9241-210 human-centered design process. Source: ISO9241.

Participatory Design

Participatory design (PD) keeps UCD as its foundation, but postulates that, because the system affects how users work, users themselves should take part in designing that system, i.e. responders must be part of the design team.

PD is ideally suited to emergency response. The responders' mistrust against IT can be entirely overcome by letting them shape the new tools. This way, the resulting product is "designed by them" as opposed to "forced upon them". The responders who participate in the design effort also become the initial, most vocal supporters of the new product. Such "social proof" leads to much higher acceptance rates than mandatory usage (Venkatesh and Davis 2000).

METHODS FOR DESIGN AND DEVELOPMENT

The following methods, grouped below by the step of UCD in which they are used, have been the most effective, in our experience, for the design and development of complex systems in emergency response. For deeper insights and details on the methods, readers are suggested to consult (Hollnagel 2013; Rasmussen et al. 1994; Endsley 2011).

Methods for analysing the context of use

Methods for context analysis can be broadly organized into two categories: analytic methods, whose basis is the analysis of formal documents and other available data, and ethnographic methods, whose basis is inquiry by interacting with users and their environment. Analytic methods are good at finding out the "formal" context, or how things should be done "by the book", but are blind to the informal "bending of the rules" by practitioners in the real world. Ethnographic methods are good at finding out how things are really done on the ground (i.e. informally), but they are blind to those requirements and processes that practitioners neglect or circumvent. Analytic and ethnographic methods must always be used together, because only so can all user needs and requirements towards a tool or system be identified[1]. Details on the best ways to combine the proposed methods under a tight budget can be found in (Elmasllari 2018a).

Analytic methods

Document analysis focuses on *written* documents and rules, for example laws, standards, process descriptions, codes of conduct, etc. These are necessary for understanding what would be a legally acceptable solution. **Literature research**, instead, learns from existing research and production efforts, i.e. from the experience, insights, and mistakes of others. Both methods should be used together in order to identify "spaces of opportunity" – areas where new approaches can be tried without conflicting with existing rules.

[1] Not all needs are equally easy to identify. Explicit needs, such as "The stretcher must be 2m long" are easily recalled and expressed by users when you ask them. Observable needs are not expressed in words, but they are obvious to an observer, e.g. "The stretcher must have a handle". The so-called tacit and latent needs are the most difficult to identify: users either cannot express them in words, or they are not even aware of having such a need.

Ethnographic methods

It is only thanks to informal, gray-area behavior, that organizations – especially emergency response organisations – can function. Understanding this behavior is crucial and can be facilitated by the ethnographic methods below.

The study of **incident reports** and **ER case evaluations** straddles the border between analytic and ethnographic methods. It is obviously similar to document analysis, but due to the detailed nature of incident inquiries and case evaluations, a good amount of ethnographic information is included. As a system designer, these reports do a great job of teaching you about past failures and events, but include little detail about behaviors that have not (yet) caused an incident or are not (yet) seen as problematic. Additionally, these reports can never transmit the visceral feeling and first-hand experience of the context, which is extremely helpful for complex system designers. This feeling and experience must be acquired through one or more of the methods below.

Observation methods (Participant and Non-participant Observation) are based on observing users as they go about their work. Behavior and movement patterns, tools, and interactions among users are noticed and documented. A **non-participant observer** tries to not influence the users' actions in any way. In **participant observation**, the observer takes part in the process as a guest and can ask questions, can experience the same physical and emotional environment, can listen to the communications more closely, and can achieve a holistic understanding of the users and their context. Participant observation is good for finding out latent and tacit needs, whereas non-participant observation uncovers the observable needs. In our experience, participant observation is best when the time for research is short and there are not many opportunities to observe responders from afar. In addition, participant observation helps with creating a rapport with the responders.

Observation-based methods have two drawbacks: i) the observer's own background and emotions may influence how he/she *interprets* the observed events and ii) the results may be tightly related to the individual responder, i.e., they may be non-generalizable.

Interviews span the complete spectrum from informal and spontaneous, to formal, with a list of questions known in advance to the subject. Two techniques, semi-structured interviews and contextual inquiries, have proven to be especially useful for understanding the context of emergency response.

Semi-structured interviews are built around a list of questions drafted before the interview, based on document research, prior knowledge of the context, or standardized question sets, e.g., (DAkkS 2010). The order of the questions is not important; they are just a checklist of what not to forget to ask.

The **contextual inquiry** method is a variation of an interview that is appropriate for tacit needs, i.e., needs that cannot be verbalized. The responder is interviewed in his or her work environment, while working. The researcher or designer becomes thus an "apprentice", asking questions and learning how to do the work. The needs and behaviors that responders take for granted because of their experience, become obvious and explicit to the researcher who is struggling to learn. As a beneficial side effect, contextual inquiries help establish trust and rapport with responders, because they feel more at ease "teaching an apprentice" than being interviewed.

Interview-based methods require a skilled interviewer (Hamill 2016). Even so, interview write-ups should always be validated with the responders, so that they can correct misunderstandings. To maximize the amount of useful data, interview subjects should be carefully chosen to have as diverse fields of expertise as possible, but they should also span all levels of experience. It is counterproductive to interview, e.g. only very experienced responders, because then the needs of younger or less experienced ones would be ignored.

Affinity diagramming, sometimes known as **card sorting**, is a method in which keywords that come up during discussions, interviews, observations, and other activities are first written on post-it notes, then grouped on a whiteboard according to similarity and other relatedness criteria (see figure 3). This helps identify topics of particular importance. We have had very good results organizing affinity diagramming "workshops", where we invite several emergency responders *from various backgrounds* and let *them* group the post-its. Because of the participants' different backgrounds and viewpoints, the sorting and grouping stimulates discussions about how the topics influence their work and how they really relate to each other. This provided us with much more domain detail than we could have inferred by interviews and observations alone.

Participatory Design methods for analysing the context of use

The methods presented below *require* the participation of responders in the design and development team and help elicit expertise and ideas from the responders themselves. For further approaches, see also (Klann 2007).

A **focus group** is a discussion with a small group of participants, which centers ("focuses") on certain topics and questions of interest to the designer or developer. Focus groups have an inherent advantage over interviews, because

Figure 3. An affinity diagramming session (left) and resulting topic relations (right).

they highlight important points better. When doing an interview, the researcher may not recognize some points as important, but those same points will be obvious in a focus group: they will stimulate lively discussion, related thoughts, and experience exchanges among the participants.

Our experience using the focus group technique with emergency responders showed that it is best to a) invite responders from different backgrounds and response entities, but b) at the same level of experience and c) at the same level of "power" or hierarchy within the respective organisations. Point a, having experts from different backgrounds, ensures that the discussed topics will be new or unfamiliar to some of the participants. The needs that are tacit or latent for the "experts" of one field will be explicit – hence verbalizable – for participants from the other fields. Points b and c, having the "same power level" and "same experience level", are necessary so that participants can discuss as equals and are not shy to express their thoughts in front of higher-status peers.

Just like interviews, focus groups require a skilled moderator. The knowledge achieved from focus groups should be verified by testing a prototype or by administering questionnaires to a larger group of users. Academic literature points out that people in focus groups tend to give "socially desirable" answers and skirt around controversial topics, but we have found emergency responders to be immune to this problem. It is, after all, part of their job to take the right action, even when it is not socially desirable or comfortable.

Sandbox sessions are discussions where participants use play figures and toys to explain their part, role, or view of a complex activity (see figure 4). This method provides a way to access users' knowledge independently of verbal or memory skills, which other methods require. Sandbox sessions are particularly useful with emergency responders, because the latter are familiar with using play figures to plan exercises.

Figure 4. Toys and play figures used in a sandbox session.

Requirements specification

While we have successfully used both "The Working Model for Usability Engineering" (ProContext Consulting GmbH 2003) and "The Volere template" (Robertson and Robertson 2018) to distill requirements from the context

analysis, we find that the exact process of extracting requirements is not as important as doing the context analysis correctly in the first place. Furthermore, our experience with different development teams has shown that each team has its own, often deeply ingrained and formalized methods for requirements engineering. As long as those methods are correct, we see little advantage in switching to another method; the cost and delays from the changeover often offset the benefits.

That said, user requirements in UCD subtly differ from traditional, system-centered requirements. UCD user requirements do not describe how the system will be implemented (e.g. "The system must have a textbox for the username"), but what the user must be able to do at the system when it is implemented (e.g. "At the system the user must be able to input his identity"). The distinction is powerful: whereas system-centered requirements define one single solution (the textbox), user-centered requirements define the outcome but allow for multiple solution possibilities (textbox, voice, fingerprint, etc.). We have found that the "Working Model" from (ProContext Consulting GmbH 2003), despite a steeper learning curve at the beginning, does a better job of forcing the designer to think in user-requirement terms and to see things from the user's point of view. The model, therefore, makes visible many more design opportunities that would otherwise be missed.

Methods for prototyping

Prototyping is required by the UCD process, and is, in our view, indispensable when designing tools for emergency response.

Scenarios are the simplest prototypes: a high-level, textual description of how a proposed tool can be used to fulfill a certain task. **Storyboards** do the same job as scenarios, but are presented as a drawn comic strip. They encourage visual thinking and can present spatial and physical-size relationships much better, e.g. the size or handling of the tool or system. Both methods invite critique and feedback from users and help understand domain requirements better. We have successfully used both scenarios and storyboards in our work with emergency responders, but we found these techniques to be most useful in the first iterations of the process, for presenting initial ideas. For later iterations we found that observation, focus groups, and contextual inquiry worked much better.

Interface sketches, **wireframes**, and **physical prototypes** make ideas concrete and graspable, both physically and figuratively speaking. They set a baseline for discussion between users and developers, they help train users, and, when created via participatory design, they make users accept and advertise the system to their peers instead of opposing it. Prototypes can (and should) be created at various levels of fidelity, from simple sketches on paper, to mock-ups of interfaces and devices with simple materials, to partially-implemented IT systems. The level of fidelity depends on the phase of development (earlier = lower fidelity) and on the questions for which developers need answers (rough estimates = lower fidelity; detailed questions and interactions = higher fidelity).

It is crucial to see the prototype as a throw-away item; the only features implemented in the prototype should be the ones necessary for getting an answer to specific questions about the domain and user needs. The prototype should look unfinished, cheap, temporary, and open to criticism; if it "looks finished" or "looks too good", users will withhold negative feedback in order to "be nice to the designer".

Methods for evaluation

The **Scenario Walkthrough** method is the cheapest, easiest method to evaluate the design of a tool or system. It consists in having one or two domain experts enact a typical task with the tool and noting difficulties or inconsistencies. The evaluation is usually done in a lab or office, not necessarily in the real environment where the system will be used. It is crucial that the experts have extensive and practical knowledge of the emergency response domain, because nobody else can put themselves in the responders' shoes.

Prototype workstations are stands in a simulated "fair", where all the developed prototypes are shown and "pitched" to small, multidisciplinary groups of domain experts and users (see figure 5). The experts give feedback and critique the proposed system, pointing out both positive features to be kept and problems to be solved. The "prototype workstations" method is more intensive than simple scenario walkthroughs, but it delivers much more feedback and can point out many more problems, thanks to its multidisciplinary approach.

As reported in (ISO9241) and (Simon 1962), the complex behavior and problems of a system do not stem from any single part in isolation, but from the interplay between the parts: users, tools, tasks, and the environment. By the above reasoning, to properly test a new tool or IT system for emergency response, the *actual users* must *use* the tool in the *actual context* to do their *actual job*. This is called **user testing under realistic conditions** and is the single most important of all evaluation methods used when designing for emergency response. Unlike business systems, which can be tested in a lab, testing emergency response tools in a lab is worthless. The pain, suffering, destruction,

Figure 5. A "Prototype workstations" session.

and chaos that one typically finds in a crisis area create heightened levels of stress that alter the responder's behavior or his/her mental ability, so that test results gathered in the lab are not transferrable to the actual incident field.

As a staple method of usability research, **user testing with thinking aloud** is distinguished by having users verbalize their thoughts *while* working with the tool or system. This allows the researcher to notice discrepancies between the user's mental model (i.e. the user's expectations) and the actual implementation. The method is not appropriate in task-loaded environments, or when the user is hurrying, because the user's behavior, speed, and actions are influenced or slowed down by having to think aloud. Such environments, which include the front lines of emergency response, benefit most from **silent, non-participatory observation**, combined with a **retrospective review**. The latter is just an interview: After having observed the responder work with the new tool or IT system, the researcher asks questions to clarify what was going on at certain notable points during the observation, esp. if the user seemed to have problems with the tool.

As a final note on evaluation, it is tempting to test prototypes only with the responders that are part of the design team (assuming participatory design). This kind of testing is indeed cheaper, but is guaranteed to give wrong results, because those responders know the prototype too well. For this reason, testing is always done with responders from outside the development team.

CONCLUSION

While there is no doubt that IT can revolutionize emergency response, practitioners have made it clear that IT tools and systems being offered to emergency responders are not satisfactory and helpful enough to be widely accepted. Existing research, too, has confirmed that the causes of rejection lie with the IT systems themselves (Paul et al. 2008; Orthner et al. 2005; Adler et al. 2012; Ammenwerth et al. 2006; Elmasllari and Reiners 2017; Elmasllari 2018b). The present paper posits that the root of the problem lies in the wrong or insufficient context and requirements analysis. This, in turn, stems from using development methodologies that are not suitable for the emergency response domain.

As a special characteristic of emergency response, we argued that the response effort is a complex, adaptive, socio-technical system. A reductionist, top-down mindset and system architecture, as is typical from common IT engineering, is counterproductive for this domain. A holistic approach which takes both social and technical parts of the system into account was argued to be necessary.

This paper presented two such holistic approaches, which we have successfully used in designing for emergency response and other complex systems. A variety of concrete methods and techniques were also presented together with their drawbacks, our critique on them, and our experience on when and how they could be best used. Far from being a detailed tutorial on any particular technique, this paper positions itself as a high-level analysis of the how, when, why, and what approaches and methods to use when designing IT systems for emergency response.

ACKNOWLEDGEMENTS

This work was carried out under the EU FP7 BRIDGE Project, Grant No. 261817, and the EU Horizon 2020 MONICA Project, Grant No. 732350.

REFERENCES

Adler, C., Krüsmann, M., Greiner-Mai, T., Donner, A., Chaves, J. M., and Estrem, A. V. (2011). "IT-Supported Management of Mass Casualty Incidents: The e-Triage Project". In: *8th International ISCRAM Conference*.

Adler, T., Jakob, L., and Krüsmann, M. (2012). "Die Einführung neuer Technologien im Rettungsdienst - Akzeptanzforschung mit GABEK® dargestellt am Projekt e-Triage". In: *GABEK V: Werte in Organisationen und Gesellschaft*. Innsbruck u.a.: StudienVerlag, pp. 307–324.

Ammenwerth, E., Iller, C., and Mahler, C. (2006). "IT-adoption and the interaction of task, technology and individuals: a fit framework and a case study". In: *BMC Medical Informatics and Decision Making* 6.1, pp. 1–13.

DAkkS (2010). *Leitfaden Usability*. 71 SD 2 007 A1. DAkkS.

Ehn, P. (2008). "Participation in Design Things". In: *Proceedings of the Tenth Anniversary Conference on Participatory Design 2008*. PDC '08. Bloomington, Indiana: Indiana University, pp. 92–101.

Elmasllari, E. (2018a). "A framework for the successful design and deployment of electronic triage systems". PhD thesis. RWTH Aachen.

Elmasllari, E. (2018b). "Why IT systems for emergency response get rejected: examining responders' attitude to IT". In: *Proceedings of the 15th ISCRAM Conference*. Rochester, NY, USA.

Elmasllari, E. and Reiners, R. (2017). "Learning From Non-Acceptance: Design Dimensions for User Acceptance of E-Triage Systems". In: *Proceedings of ISCRAM 2017*.

Endsley, M. R. (2011). *Designing for Situation Awareness: An Approach to User-Centered Design, Second Edition*. 2nd. Boca Raton, FL, USA: CRC Press, Inc.

Fowler, M. (2002). *The XP 2002 Conference*.

Ganz, A., Schafer, J., Yu, X., Lord, G., Burstein, J., and Ciottone, G. R. (2013). "Real-time scalable resource tracking framework (DIORAMA) for mass casualty incidents". In: *International Journal of E-Health and Medical Communications (IJEHMC)* 4.2, pp. 34–49.

Hamill, H. (2016). *Interview Methodology*.

Holland, J. H. (1995). *Hidden Order: How Adaptability Builds Complexity*.

Hollnagel, E. (2013). *Resilience engineering in practice: a guidebook*. Ashgate Publishing, Ltd.

ISO9241. *ISO9241: Ergonomics of Human System Interaction*. International Organization for Standardization.

Jennings, E. A., Arlikatti, S., Andrew, S. A., and Kim, K. (2017). "Adoption of information and communication technologies (ICTs) by local emergency management agencies in the United States". In: *International Review of Public Administration* 22.2, pp. 193–210. eprint: https://doi.org/10.1080/12294659.2017.1323481.

Klann, M. (2007). "Playing with Fire: User-Centered Design of Wearable Computing for Emergency Response". In: *Mobile Response*. Ed. by J. Löffler and M. Klann. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 116–125.

Norman, D. (1988). *The Psychology of Everyday Things*. The Psychology of Everyday Things. Basic Books.

Norman, D. A. and Draper, S. W. (1986). *User Centered System Design; New Perspectives on Human-Computer Interaction*. Hillsdale, NJ, USA: L. Erlbaum Associates Inc.

Orthner, H., Mishra, N., Terndrup, T., Acker, J., Grimes, G., Gemmill, J., and Battles, M. (2005). "Information Infrastructure for Emergency Medical Services". In: *AMIA annual symposium proceedings*, p. 1067.

Paul, S. A., Reddy, M., Abraham, J., and DeFlitch, C. (2008). "The Usefulness of Information and Communication Technologies in Crisis Response". In: *AMIA annual symposium proceedings*, pp. 561–565.

ProContext Consulting GmbH (2003). *Das Arbeitsmodell des Usability Engineering*. URL: http://www.procontext.de/ueber-procontext/methodik.html.

Rasmussen, J., Pejtersen, A. M., and Goodstein, L. P. (1994). *Cognitive Systems Engineering*. New York, NY, USA: John Wiley & Sons, Inc.

Ritter, F., Baxter, G., and Churchill, E. (2014). "Foundations for Designing User-Centered Systems: What System Designers Need to Know about People". In: Springer London. Chap. 2, pp. 33–54.

Robertson, J. and Robertson, S. (2018). *Volere Requirements Specification Template*. Tech. rep. Atlantic Systems Guild.

Schmitt, T., Council, N. R., Rao, R. R., and Eisenberg, J. (2007). *Improving Disaster Management: The Role of IT in Mitigation, Preparedness, Response, and Recovery*. Washington, DC, USA: National Academy Press.

Shapiro, D. (2005). "Participatory Design: The Will to Succeed". In: *Proceedings of the 4th Decennial Conference on Critical Computing: Between Sense and Sensibility*. CC '05. Aarhus, Denmark: ACM, pp. 29–38.

Simon, H. A. (1962). "The Architecture of Complexity". In: *Proceedings of the American Philosophical Society* 106.6, pp. 467–482.

Slavin, K. (2016). "Design as Participation". In: *Journal of Design and Science*.

SW Thames (1993). *Report of the Inquiry Into The London Ambulance Service*. Tech. rep. South West Thames Regional Health Authority.

Tapia, A. (2018). *Keynote at the ISCRAM 2018 conference*. Keynote.

The Standish Group (1995). *CHAOS Report*. Tech. rep. The Standish Group.

Turoff, M., Chumer, M., Walle, B. V. de, and Yao, X. (2004). "The design of a dynamic emergency response management information system (DERMIS)". In: *Journal of Information Technology Theory and Application (JITTA)* 5.4, p. 3.

Venkatesh, V. and Davis, F. D. (2000). "A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies". In: *Manage. Sci.* 46.2, pp. 186–204.

Visciola, M. (2003). "Reflections on the User Centered Design (UCD) Perspective in Research on Wireless Applications". In: *Ubiquity* 2003.April, pp. 1–1.

Waldrop, M. M. (1993). *Complexity: The emerging science at the edge of order and chaos*. Simon and Schuster.

Wu, P. F. (2009). "User acceptance of emergency alert technology: A case study". In: *Proceedings of the 6th International ISCRAM Conference–Gothenburg, Sweden*.

Structured crisis training with mixed-reality simulations

Jo Erskine Hannay
University of Oslo, Department of Technology Systems
j.e.hannay@its.uio.no

Yelte Kikke
University of Oslo, Department of Technology Systems
yelte.kikke@its.uio.no

ABSTRACT

We argue that current technology for crisis training does not explicitly cater well enough for managing training objectives and skill building metrics throughout the lifespan of training. We suggest how successful crisis training may be enabled by interoperating next-generation exercise management tools with mixed-reality simulations. We propose an architecture consisting of (1) a front-end in which training objectives, essential skills, corresponding events and metrics can be declared, (2) a back-end consisting of simulations that implement the events and metrics and (3) a middleware which transfers information between the front-end and back-end to enable semi-automatic composition of the simulations and performance analysis. The purpose of this architecture is to facilitate learning through the principles of deliberate practice. We indicate where emerging technologies are necessary to achieve this.

Keywords

Exercise management, Mixed reality, Simulation, Deliberate practice, ADL, MSaaS, C2Sim, ExConSim, ExManSim

INTRODUCTION

Civilian and military crisis management organizations regularly conduct training and large-scale exercises. For example, over 50,000 participants, 250 aircraft and 65 vessels from more than 30 nations recently partook in NATO's Trident Juncture 18 exercise. More than 300,000 soldiers, 36,000 military vehicles, 1000 aircraft, helicopters and drones, and 80 warships from three nations joined the Vostok-2018 in Eastern Siberia. On the civilian side, most large cities regularly conduct city- or region-wide exercises that involve fire, law enforcement and healthcare organizations over the course of several days.

Although often deemed highly successful, such exercises are also extremely costly and often infringe on society in unacceptable ways. Moreover, although there is a lack of systematic observations as to the effects of exercises, discussions with subject matter experts, trainers and observers suggest clearly that exercises often do not have clear and structured training objectives, that lessons identified are recorded in an *ad hoc* manner, and that lessons identified are often not transformed into lessons learned. These are unfortunate shortcomings to the demands that heightened levels of readiness pose in today's global situation.

The use of simulations for training and exercises has been investigated over several decades by industry, academia and practitioners. Indeed, simulations are an integral part of many training and exercise regimes in both the civilian and military domains. Well-known examples are flight simulators and various vehicle and equipment simulators for safe operator training. Moreover, planning, coordination, collaboration and decision-making protocols are trained using various computer-aided simulations. This happens in dedicated training events, but is also done in conjunction with large-scale exercises such as those mentioned above. Trainers use exercise control (ExCon) systems to administer events and injects in a timely manner. Simulations are perceived to save time, cost and increase quality for training and enable training not possible otherwise (NATO Modelling and Simulation Group 2012; NATO Research and Technology Organization 2010; Hannay, Brathen, et al. 2015).

In all this extensive exercise and training activity, there is an explicit tool focus on *what* should happen in exercise and training scenarios. The explicit mention of *why* is not prevalent; that is, the skills underlying task performance – the actual target of training – are not addressed to the same extent in exercise management tools.

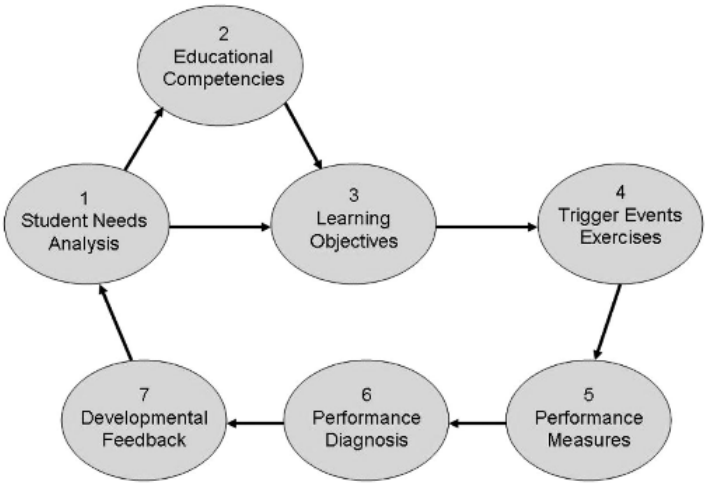


Figure 1. Simulation-based training loop (Salas et al. 2009)

THE INTENT IN SIMULATION-BASED TRAINING

The, by now, hackneyed simulation-based training loop diagram due to (Salas et al. 2009) proposes how simulation-based training should be an incremental and reflective process, rooted on learning objectives.

Anecdotal evidence suggests that this loop in many cases is broken. A governmental Emergency Planning College recently summarized participants' perceptions of exercises (which are so-called *Live* simulations) as follows; see also (Pollestad and Steinnes 2012):

- Exercises have little effect
  - Continuity:
    - Exercises are conducted in isolation and without any connection to earlier exercises
    - Experiences from one person or group are not used by others
    - Lessons identified are not processed further to lessons learned
  - Objectives
    - Exercise objectives are not formulated clearly
    - Objectives are not differentiated on roles
- Exercises are scary
  - Exercises are given as tests or "exams", rather than as a means for improving performance
  - Challenges are given that participants do not have the means to master
- Exercises are time-consuming and demand excessive resources
  - Exercises are something one does not really have time, nor resources, to conduct
  - The benefit of conducting an exercise does not justify the cost.
- Exercises are difficult
  - Exercises are difficult to plan and organize
  - Exercise objectives, events and scenarios are difficult to define
  - Exercise results are hard to grasp

These anti-patterns for learning in large exercises are also found in day-to-day training. Most simulators and simulations are capable of recording a lot of relevant data. We are aware of a number of instances where such data are not used at all; seemingly because there are neither routines for collecting data, nor tools at hand to analyse data. Also, clear learning objectives are a prerequisite to determine what data to collect. Further, the notion of continuity with the possibility to compare training results over time is often not rooted in the organization. Lessons are identified, but there are insufficient mechanisms for transforming those into lessons learned and integrating them into the daily work (Skarpaas and Kristiansen 2010).

In the following, we argue by design that current technology in use does not give enough support for keeping the simulation-based training loop alive.

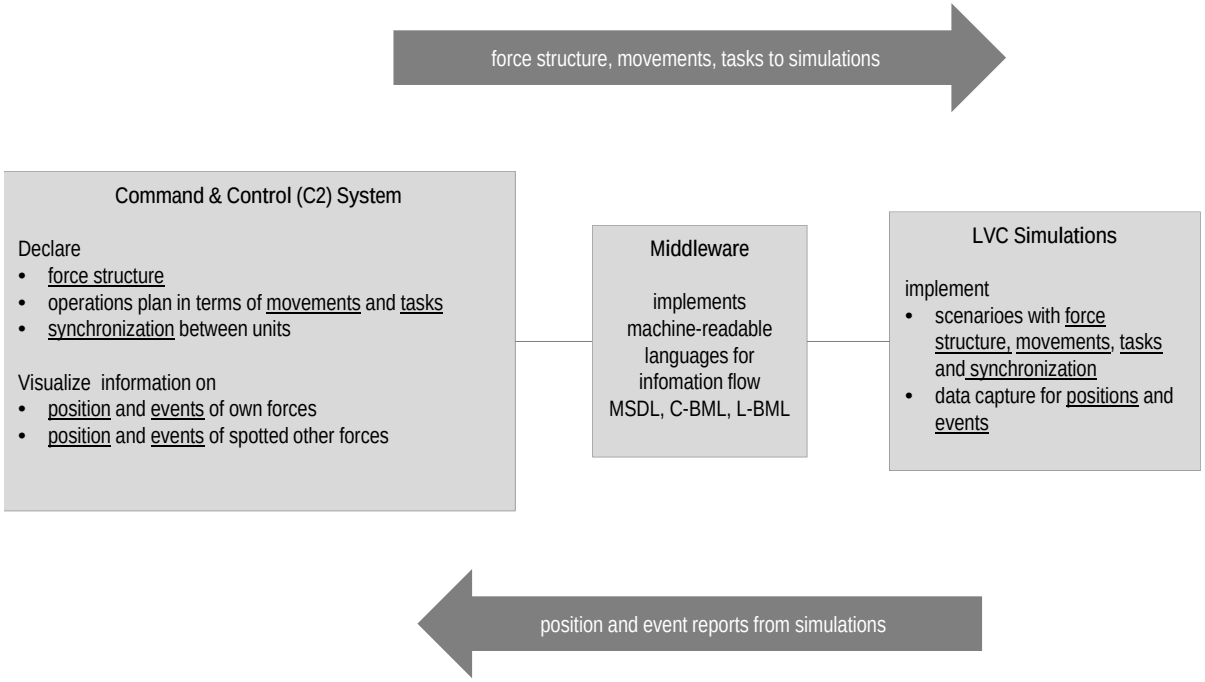


Figure 2. C2Sim configuration

COMMAND & CONTROL WITH SIMULATIONS

Command and control (C2) information systems (C2IS) are used for planning, commanding and monitoring military operations, usually in a geographical map-based user interface. There are similar systems for the civilian sector. In the defence domain, substantial effort is being laid down to enable C2IS to interoperate with simulations (Simulation Interoperability Standards Organization 2014b; Tolk 2012a; Tolk 2012b). The purpose of this is that personnel can use their normal working tools when participating in simulation-based training. Thus, machine-readable languages have been developed, so that force structures, unit movements and task that are specified in the C2IS can be automatically sent via these languages to a simulation, where the planned operation can be simulated. C2IS also receive position and event updates from the simulation, and can render these to users on the C2IS map; see Figure 2. In particular, the Military Scenario Definition Language (MSDL) (Simulation Interoperability Standards Organization 2008) is a standard for describing force structures and their initial positions, the Coalition Battle Management Language (C-BML) (Simulation Interoperability Standards Organization 2014a) is a formalized language for expressing a commander's plans, orders and reports across C2IS, simulation systems and autonomous systems, and Low-level BML (L-BML) (Alstad and Mevassvik 2013) is a language to specify more detailed movements and tasks to simulation entities from a break-down of C-BML orders (Løvlid et al. 2018). A number of system demonstrators have been developed to explore the concept; e.g., (Pullen et al. 2012; Allen and Schroeder 2011; Coolahan and Allen 2011; Bruvoll et al. 2015).

Efforts toward further interoperability between C2IS and simulation systems are consolidated in a C2Sim initiative (Simulation Interoperability Standards Organization 2014b; Heffner et al. 2014), now also involving ontologies for enhanced conceptual expressiveness at the machine level (Singapogu et al. 2016). These efforts build on earlier work based on large data models such as the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM) (NATO standard STANAG 5525) and its successor, the Multilateral Interoperability Program Information Model (MIM) (Gerz and Bau 2016) that specify the minimum set of data that needs to be exchanged in coalition or multinational operations.

All this makes it possible to achieve interoperability between C2IS and simulation systems. As is evident from the above, there is a substantial focus on being able to represent entities and tasks accurately in the military domains. However, even though the initial motivation for all this was training, there is no explicit mention of training objectives, what skills to be trained or skill performance metrics. Indeed, besides interoperability between C2IS and simulations, C2Sim languages are now also designed for connecting C2IS themselves and for controlling and monitoring unmanned vehicles from C2IS.

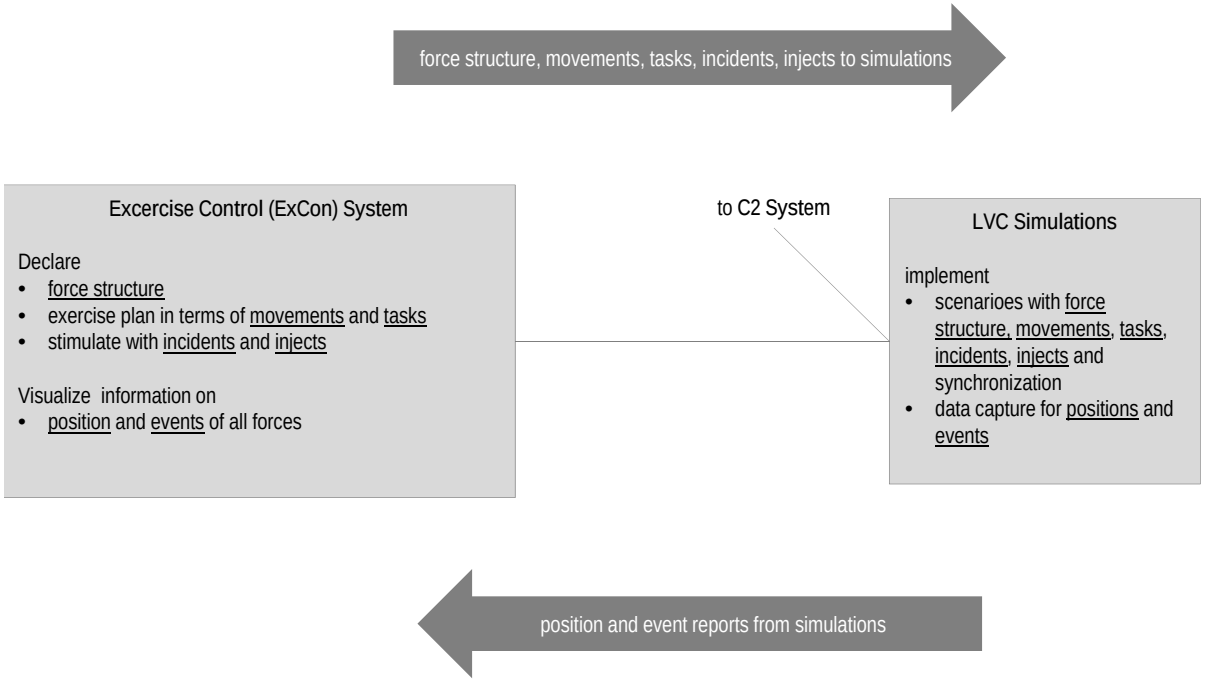


Figure 3. ExConSim configuration

EXERCISE CONTROL WITH SIMULATIONS

Of course, the C2Sim initiatives above are extremely important. Simulations have to be sufficiently detailed and accurate to be of any value to training. Usually, trainer staff have their own consoles in which they control and monitor exercises and training using an exercise control (ExCon) system integrated with simulations (ExConSim); see Figure 3. These are often direct front-ends to simulations, but can also be third-party products designed to administrate training simulations. Thus, while trainees in the C2Sim configuration above participate in a simulation via their C2IS, trainers monitor and control the simulation via the ExCon system.Trainers can stimulate training with incidents and injects, but ExCon systems usually do not have functionality to define training objectives or any higher-level functionality to support, say, learning principles. They usually have functionality to record entity positions and events and can thus present reviews based on this data.

EXERCISE MANAGEMENT WITH SIMULATIONS

Beyond C2Sim and ExConSim, there is a need for a more explicit approach to support the simulation-based training loop and to alleviate the problems that seem to be integral to crisis training. We now outline an architecture which, by design, addresses the shortcomings in the preceding architectures. Figure 4 presents this architecture; where an exercise management tool interoperates with mixed-reality simulations. The architecture consists of three main components: A front-end, a back-end and a middleware component.

Front-end

The front-end consists of a user-facing system (a web application for easy access on portable devices) that allows exercise management staff

- to declare training objectives,
- to select which essential skills to be trained to reach those objectives,
- to select events to stimulate development of those essential skills,
- to select corresponding metrics for measuring essential skill performance in the events and
- to compose vignettes and scenarios from the selected events.

This design promotes the idea of composing exercise and training scenarios and vignettes (sub-scenarios) from a selection of predefined events that are designed to stimulate given essential skills. The events have associated skill metrics. Scenario composition can range from manual (Simulation Interoperability Standards Organization 2018) through semi-automatic to automatic; e.g., (Martin et al. 2009) or (Zook et al. 2012) who describe a method for

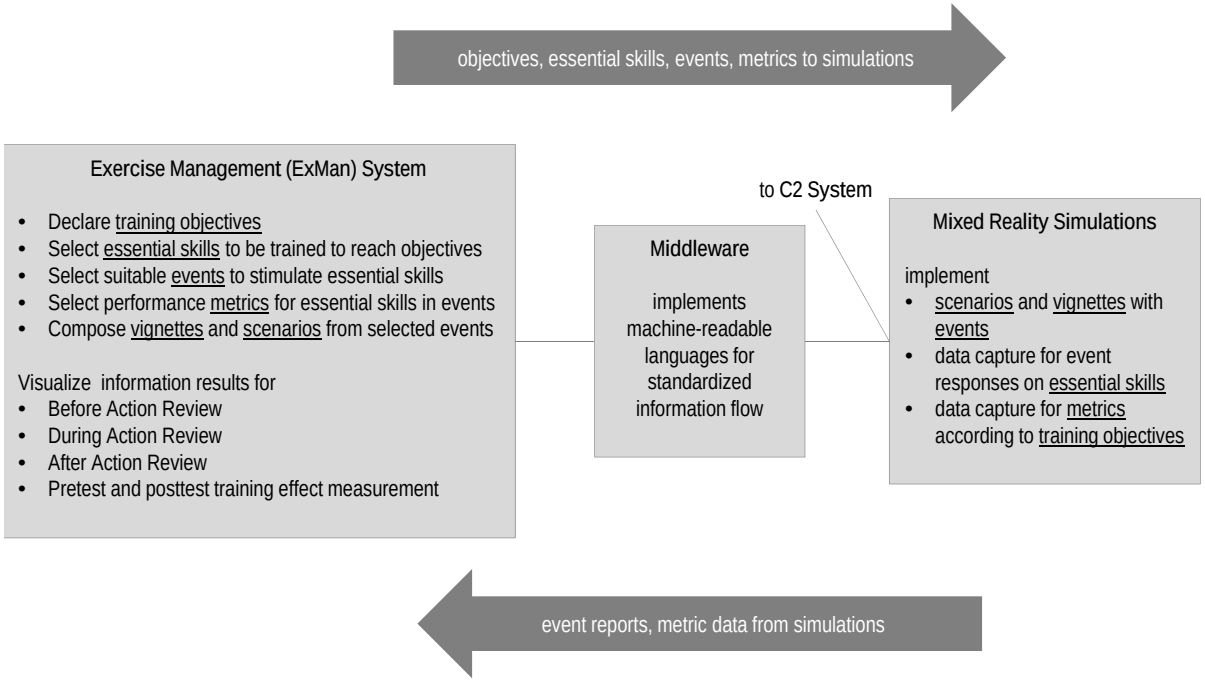


Figure 4. ExManSim configuration

generating scenarios using combinatorial optimization: An algorithm constructs a scenario by choosing events and determines the appropriateness of the scenario using a fit function over training objectives. Events may be designated as *mandatory* or *preferred*, giving degrees of variety in the generated scenarios.

When events and their associated skill metrics are combined, a new combined event and combined metric is generated. Also a skill may have varying metrics according to roles and combination of roles. How this should be done in the face of combinatorial explosion and validity is a topic currently under investigation. Another topic under investigation is how an essential skill as a generic construct; e.g., acquiring shared situation awareness, should be instantiated in a range of domain-specific events, with some sort of reuse of the concept and associated metrics in the various domains.

The front-end also allows exercise management to visualize information for use in

- Before-action review (BAR); in which a training session or an exercise can be pre-run in a simulation for validation of the consistency and coherency between objectives, skills, events and metrics.
- During-action review (DAR); in which identified learning and performance issues can be addressed immediately during training and exercise in simulations, thereby giving trainees direct feedback.
- After-action review (AAR); in which learning and performance issues can be analyzed and addressed in after action simulations; thereby turning identified lessons identified into lessons learned immediately after training or an exercise.
- Pretest and posttest effect measurement; in which essential skill performance can be measured in controlled simulations before and after training and exercises for measuring the effect of training and exercise.

The purpose of these functions is to support *deliberate practice* (Ericsson 2006); a framework that addresses the short-comings of "learning on the job", by a strong focus on difficult aspects, immediate and tailored feedback (by a coach or computer-adaptive system), followed by tailored re-trials integrated into the larger sequence of tasks.

Further, it is common to emphasise the importance of training on realistic tasks in a realistic environment. However, research has shown that training that simply reflects actual circumstances is not sufficient (Shadrick and Lussier 2009). Using artificial, rather than realistic, elements in training is common in other domains. For example, an athlete will not spend all her training time practising the exact sequence of actions she will perform during competition, but will spend considerable time on specific training of muscle groups, on mental preparation, and even on other sport disciplines. A musician will repeatedly focus on difficult passages, thus engaging in artificial behaviour compared to an actual performance, while still using his actual instrument.

For tactical decision making, normal realistic training is, in general, insufficient, because it does not target the development of decision-making skills (Shadrick and Lussier 2009). Judgement and decision tasks are often

so-called inconsistent (different people develop differing successful strategies) (Campbell et al. 1993; Campbell 1990) or ill-defined (hard even to define successful strategies) (Johnson 1988; Simon 1973; Reitman 1965; Voss and Post 1988). Research shows that practitioners on inconsistent and ill-defined tasks may spend half their careers apparently *not* learning and *not* improving performance beyond, perhaps, a very narrow subset of (consistent) tasks. Instead, the idea is to train adaptability; i.e., how to adapt to unknown and surprising situations. In line with this, the notion of *adaptive thinking* has been adopted in the defence domain for tactical decision making (Shadrick, Lussier, and Hinkle 2005; Shadrick and Lussier 2009) based on a concept of adaptive job performance (Pulakos et al. 2000).

Thus, it may be necessary to engage in artificially enhanced tasks to heighten performance. Such tasks are the result of *task analyses* and depend on the actual task at hand. Particularly relevant for judgement and decision-making tasks, *cognitive task analysis* uncovers a range of unconscious processes as well as how decision-makers of varying degrees of proficiency think (Mussweiler 2003; Gigerenzer and Todd 1999; Klein 1997; Kahneman and Frederick 2004). The ExManSim architecture has a focus on events targeted at essential skills, and the idea is that training and exercises can be explicitly planned with events containing such artificially enhanced tasks when appropriate.

Back-end

The back-end consists of mixed-reality simulations. Simulations are often divided into *Live*, *Virtual* and *Constructive*. *Live* simulation has live personnel using real equipment, but where, e.g., live ammunition is replaced by laser pulses and detectors; all networked to combine event and positional data for a comprehensive digitized view of events. *Virtual* simulation has live personnel in a virtual environment (e.g., flight simulators and vehicle manoeuvre in gaming), and *Constructive* simulation has totally computer-simulated entities. Combining the three modes in so-called LVC simulation in a distributed system is assumed to increase training capabilities and training effect. Using appropriate standards such as the High Level Architecture (HLA) (IEEE Standards Association 2010) or the Distributed Interactive Simulation (DIS) standard (IEEE Standards Association 2015), all entities and movements in the combined simulation can be seen in the various *Virtual* and *Constructive* simulations (Hannay, Mevassvik, et al. 2014). *Live* players can see simulated entities in their C2IS (using C2Sim) (Hannay, Mevassvik, et al. 2014), and when equipped with augmented reality technology, may also see and interact with simulated entities in their field of view. This combination of LVC simulation modes with player interaction in all three modes constitutes *mixed reality* simulation.

In addition to the the general benefit/cost arguments in favour of simulation-based training, simulation is essential for conducting artificial tasks and deliberate practice regimes. Moreover, mixed reality simulations are necessary when crisis response personnel need to train in simulations with their regular working equipment. Personnel training for road tunnel fires would not enter a burning tunnel in real life but would train in a virtual simulation. Virtual reality headsets may be used for better immersion, but to enable trainees to use their normal equipment such as radios, firefighting equipment, first aid equipment, etc., they would rather use augmented reality headsets, so that they can see and interact with their real surroundings and tools and interact with the virtual simulation at the same time.

Once a scenario has been composed in the front-end, the simulations for running the scenario must be composed quickly and accurately. Today, it typically takes months or even years to develop simulations; see e.g., (Edgren 2012). This is a serious disabler for generating simulations that match differing training objectives and skills to be stimulated though appropriate events in a flexible manner. Initiatives on *Modelling and Simulation as a Service* (MSaaS) work toward setting up simulations for operations and training readily and rapidly (Hannay and van den Berg 2017; van den Berg et al. 2017; Asprusten and Hannay 2018) from simulation services. The *service* concept embodies reusability by standardization of common functionality, and composability through loose coupling and standardized service descriptions. Thus, events can be reflected by simulation services at the back-end. Then, composing events to vignettes and scenarios on the operational level in the front-end map to composing simulation services to composed simulations at the back-end.

Metrics selected in the front-end must also be implemented as data collectors and/or measurements in simulations. For example, (Cornell et al. 2007) describe an automated process for measuring human performance. A performance measurement pipeline is developed to assess human performance in virtual training, so that raw simulation output data is transformed to give meaningful event assessments. Using this, C2Sim data, say, may be transformed to event metric information in the ExManSim setup.

Middleware

The middleware component handles information flow between the exercise management system (front-end) and the simulations (back-end). As for the C2Sim configuration, machine readable languages must handle this.

ExManSim requires a language that can express not only what to do, as MSDL and C-BML do, but also for what objectives and for what training effect one is doing those things. This requires additional language structures. An immediate thought is to combine C-BML with Experience API (xAPI); a language from the Advanced Distributed Learning (ADL) initiative (Fletcher et al. 2007) that is used to collect experiences online and offline in a structured and standardized way. This combination might be used to track a trainee's learning when using a simulation system to reach certain training objectives, since xAPI has structures to store information and results about an activity. This means one can define criteria on when performance in an event is considered successful, and one can define more advanced scoring algorithms based on that. For further pointers, see (Durlach 2018).

Example

To illustrate how the ExManSim architecture is intended to function, consider the domain of *fire crisis management*. Recent fire incidents in road tunnels give rise to a training objective "Improve communication and collaboration between first responders at the scene of road tunnel fires". One essential skill (among several others) in crisis management is *acquiring shared situation awareness* (SSA), which is the overlap in situation awareness (SA) between members of a team (Nofi 2000).

Situational awareness is defined in (Endsley 2000) as "...the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Hence, this definition can be split out in three levels (Valaker et al. 2018):

1. the position of all entities in an area of interest, regardless of their identity
2. in addition to the above, the relationships between the entities
3. in addition to the above, the possible future configurations of the entities and relationships

To stimulate the development of this essential skill in this particular domain, one conceivable event would be a collision in a road tunnel and subsequent fire with human casualties. This event requires personnel in different roles collaborating to respond to the event: Firefighters must extinguish the fire, health personnel must treat the injured and police must secure the scene. SA, and especially SSA, is crucial to execute the required tasks successfully and to create a safe working environment for all personnel. To acquire SSA, the trainees must first be aware of the relevant entities and their relevant relationships (car fire close to flammable tunnel lining) and what resources can be drawn from the other roles (SA Levels 1 and 2). Then, the trainees must understand how the situation might evolve; for example, if there is a danger of a second fire and if further civilians may become at risk (SA Level 3).

For this example, an exercise manager would use the front-end to select the domain of "fire crisis management" and declare the objective "improve communication and collaboration between first responders at the scene of road tunnel fires". The front-end then allows the exercise manager to select "acquire SSA" (and other skills that the ExManSim system supports) from a list of essential skills to be trained in that domain. For each selected essential skill, the front-end then presents a list of events (for example the "car collision event") supported by the ExManSim system. Each event has associated metrics for measuring skill performance. For "acquiring SSA", appropriate metrics would be sorted under the three categories above. To make an evolving scenario, subsequent events may be selected as well; e.g., "secondary fire in flammable material on tunnel wall".

Acquiring SSA involves several roles acting on the same events. For an impression of some of the complexity in composing metrics when combining roles even in a single event, consider again SSA: To acquire SSA, the team members must share and enquire each others individual situation awareness (ISA).

Figure 5 shows this schematically, suggesting that there are different SSA configurations depending on the number of personnel and roles involved. For example, *X123* in this example consists of the information that is available to

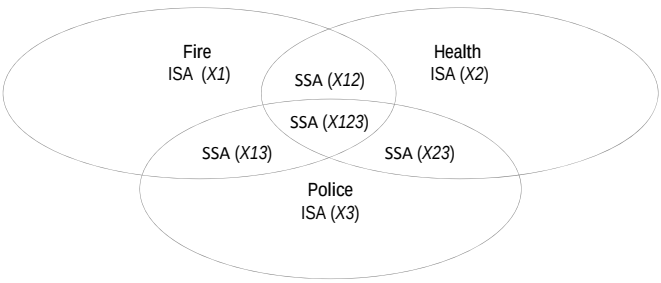


Figure 5. Schematic visualization of individual situation awareness (ISA) and shared situation awareness (SSA)

all personnel. One might think that the more information that is shared, the better. However, interviews with subject matter experts suggests otherwise: It is often the case that personnel receive too much information, resulting in lower performance. Hence, trainees should train to achieve *effective* SSA; that is, the amount and type of SSA that results in higher task performance.

Effective SSA depends on the role of a person. A task force leader may need a more extensive SSA than personnel with a more individual role. When composing SA-dedicated events into vignettes and scenarios in the front-end, effective SSA must be expressed in the combined skill metrics that result when composing those events.

At the back-end, a virtual simulation might be composed by a simulation service implementing the car collision event and a simulation service implementing the tunnel wall fire. Separate metrics services composed to measure effective SSA for each intended trainee role may be composed into the simulation. Trainees may use virtual or augmented reality equipment, or other media, depending on the need to interact with real equipment.

For information flow between the exercise management tool and the simulation, the scenario composed of the events and metrics would be transmitted in a machine-readable language to the back-end, where a simulation composer may semi-automatically compose the simulation from simulation services and metrics services. SSA skill metric information would flow back to the front-end for presentation in the various action reviews.

CONCLUSION

There is a strong focus on accurate representation of entities and events, and a paradoxical lack of focus on structures and standards that explicitly address training and learning, in architectures for simulation-based training. We propose the need for an architecture for exercise management and simulations (ExManSim). This architecture is designed to take on the challenges faced in simulation-supported exercises and training, so that the intents of simulation-based training may be realized. The architecture relies on emerging technologies within machine-readable semantic representations of events at the model level, and associated simulation services at the implementation level.

The architecture is proposed based on arguments of design. Current research is refining this architecture in collaboration with stakeholders from a range of crisis management organizations and industry. A working prototype for some of the functionality in the architecture is planned to be released in increments in the near future.

Acknowledgements

This research is funded by the Research Council of Norway under project no. 282081 “MixStrEx”. The authors are grateful to the anonymous reviewers and Ole Martin Mevassvik at FFI for helpful comments.

REFERENCES

Allen, G. W. and Schroeder, L. (2011). “Utilization of Service Oriented Architecture (SOA)-Based Commercial Standards to Address Live, Virtual, Constructive (LVC) Interoperability Challenges”. In: *Proc. Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2011*. National Training and Simulation Association.

Alstad, A. and Mevassvik, O. M. (2013). “Low-level BML”. In: *Proc. 2013 Spring Simulation Interoperability Workshop (SIW)*. Simulation Interoperability Standards Organization.

Asprusten, M. and Hannay, J. E. (2018). “Simulation-Supported Wargaming using M&S as a Service (MSaaS)”. In: *Proc. NATO Modelling and Simulation Group Symp. on Multi-National Pooling and Sharing of Simulation Resources under the M&S as a Service Paradigm (STO-MP-MSG-159)*.

Bruvoll, S., Hannay, J. E., Svendsen, G. K., Asprusten, M. L., Fauske, K. M., Kvernelv, V. B., Løvlid, R. A., and Hyndøy, J. I. (2015). “Simulation-Supported Wargaming for Analysis of Plans”. In: *Proc. NATO Modelling and Simulation Group Symp. on M&S Support to Operational Tasks Including War Gaming, Logistics, Cyber Defence (STO-MP-MSG-133)*.

Campbell, J. P. (1990). “Modeling the Performance Prediction Problem in Industrial and Organizational Psychology”. In: *Handbook of Industrial and Organizational Psychology*. Ed. by M. D. Dunnette and L. M. Hough. Vol. 1. Consulting Psychologists Press, Inc., pp. 687–732.

Campbell, J. P., McCloy, R. A., Oppler, S. H., and Sager, C. E. (1993). “A Theory of Performance”. In: *Personnel Selection in Organizations*. Ed. by N. Schmitt and W. C. Borman. Josey-Bass, pp. 35–70.

Coolahan, J. E. and Allen, G. W. (2011). “LVC Architecture Roadmap Implementation—Results of the First Two Years”. In: *Proc. 2011 Fall Simulation Interoperability Workshop (SIW)*. 11F-SIW-025. Simulation Interoperability Standards Organization.

Cornell, G., Boland, W., and Frank, G. (2007). "Automating Human Performance Measurement using XSLT in Simulation-Based Exercises". In: *Proc. Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2007*. National Training and Simulation Association.

Durlach, P. J. (2018). "Can we talk? Semantic Interoperability and the Synthetic Training Environment". In: *Proc. Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2006*. National Training and Simulation Association.

Edgren, M. G. (2012). "Cloud-Enabled Modular Services: A Framework for Cost-Effective Collaboration". In: *Proc. NATO Modelling and Simulation Group Symp. on Transforming Defence through Modelling and Simulation—Opportunities and Challenges (STO-MP-MSG-094)*.

Endsley, M. R. (2000). "Theoretical Underpinnings of Situation Awareness: A Critical Review". In: *Situation awareness analysis and measurement*. Ed. by M. R. Endsley and D. J. Garland. Lawrence Erlbaum Associates Publishers, pp. 13–32.

Ericsson, K. A. (2006). "The Influence of Experience and Deliberate Practice on the Development of Superior Expert Performance". In: *The Cambridge Handbook of Expertise and Expert Performance*. Ed. by K. A. Ericsson, N. Charness, P. J. Feltovich, and R. R. Hoffman. Cambridge Univ. Press. Chap. 38, pp. 683–703.

Fletcher, J. D., Tobias, S., and Wisher, R. A. (2007). "Learning Anytime, Anywhere: Advanced Distributed Learning and the Changing Face of Education". In: *Educational Researcher* 36.2, pp. 96–102.

Gerz, M. and Bau, N. (2016). "MIP Information Model 4.0, Semantic Interoperability in Multinational Missions". In: *Proc. 21st International Command and Control Research and Technology Symposium (ICCRTS)*.

Gigerenzer, G. and Todd, P. M., eds. (1999). *Simple Heuristics that Make Us Smart*. Oxford University Press. Chap. 4, pp. 75–95.

Hannay, J. E., Brathen, K., and Hyndøy, J. I. (2015). "On How Simulations Can Support Adaptive Thinking in Operations Planning". In: *Proc. NATO Modelling and Simulation Group Symp. on M&S Support to Operational Tasks Including War Gaming, Logistics, Cyber Defence (STO-MP-MSG-133)*.

Hannay, J. E., Mevassvik, O. M., Skjeltorp, A., and Brathen, K. (2014). "Live, Virtual, Constructive (LVC) Simulation for Land Operations Training: Concept Development & Experimentation (CD&E)". In: *Proc. NATO Modelling and Simulation Group Symp. on Integrating Modelling & Simulation in the Defence Acquisition Lifecycle and Military Training Curriculum (STO-MP-MSG-126)*.

Hannay, J. E. and van den Berg, T. W. (2017). "The NATO MSG-136 Reference Architecture for M&S as a Service". In: *Proc. NATO Modelling and Simulation Group Symp. on M&S Technologies and Standards for Enabling Alliance Interoperability and Pervasive M&S Applications (STO-MP-MSG-149)*.

Heffner, K., Mevassvik, O. M., Gautreau, B., and De Reus, N. (2014). "A Proposed Process and Toolset for Developing Standardized C2-to-Simulation Interoperability Solutions". In: *Proc. NATO Modelling and Simulation Group Symp. on Integrating Modelling & Simulation in the Defence Acquisition Lifecycle and Military Training Curriculum (STO-MP-MSG-126)*.

IEEE Standards Association (2010). *1516-2010 – IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA)*.

IEEE Standards Association (2015). *1278.2–2015 – IEEE Standard for Distributed Interactive Simulation (DIS) – Communication Services and Profiles*.

Johnson, E. J. (1988). "Expertise and Decision under Uncertainty: Performance and Process". In: *The Nature of Expertise*. Ed. by M. T. H. Chi, R. Glaser, and M. J. Farr. Lawrence Erlbaum Associates, Inc., pp. 209–228.

Kahneman, D. and Frederick, S. (2004). "A Model of Heuristic Judgment". In: *The Cambridge Handbook of Thinking and Reasoning*. Ed. by K. J. Holyoak and R. G. Morrison. Cambridge Univ. Press, pp. 267–294.

Klein, G. (1997). "Developing Expertise in Decision Making". In: *Thinking & Reasoning* 3.4, pp. 337–352.

Løvlid, R. A., Bruvoll, S., Brathen, K., and Gonzalez, A. (2018). "Modeling the behavior of a hierarchy of command agents with context-based reasoning". In: *J. Defense Modeling and Simulation: Applications, Methodology, Technology* 15.4, pp. 369–381.

Martin, G., Schatz, S., Bowers, C., Hughes, C. E., Fowlkes, J., and Nicholson, D. (2009). "Automatic Scenario Generation through Procedural Modeling for Scenario-Based Training". In: *Proc. the Human Factors and Ergonomics Society Annual Meeting* 53.26, pp. 1949–1953.

Mussweiler, T. (2003). "Comparison Processes in Social Judgment: Mechanisms and Consequences". In: *Psych. Review* 110.3, pp. 472–489.

NATO Modelling and Simulation Group (2012). *NATO Modelling and Simulation Master Plan (version 2.0)*.

NATO Research and Technology Organization (2010). *The Cost Effectiveness of Modelling and Simulation (M&S)*. Technical Report RTO-TR-MSG-031.

Nofi, A. A. (2000). *Defining and Measuring Shared Situational Awareness*. Tech. rep. CRM D0002895.A1/Final. Center for Naval Analyses.

Pollestad, B. and Steinnes, T. (2012). "Øvelse gjør mester?" MA thesis. University of Stavanger, Dept. of Media and Social Sciences.

Pulakos, E. D., Arad, S., Donovan, M. A., and Plamondon, K. E. (2000). "Adaptibility in the Work Place: Development of a Taxonomy of Adaptive Performance". In: *J. Applied Psychology* 85.4, pp. 612–624.

Pullen, J. M., Corner, D., Brook, A., Wittman, R., Mevassvik, O. M., and Alstad, A. (2012). "MSDL and C-BML Working Together for NATO MSG-085". In: *Proc. 2012 Spring Simulation Interoperability Workshop (SIW)*. 12S-SIW-045. Simulation Interoperability Standards Organization.

Reitman, W. (1965). *Cognition and Thought*. Wiley.

Salas, E., Wildman, J. L., and Piccolo, R. F. (2009). "Using Simulation-Based Training to Enhance Management Education". In: *Academy of Management Learning & Education*.

Shadrick, S. B. and Lussier, J. W. (2009). "Training Complex Cognitive Skills: A Theme-based Approach to the Development of Battlefield Skills". In: *Development of Professional Expertise*. Ed. by K. A. Ericsson. Cambridge University Press. Chap. 13, pp. 286–311.

Shadrick, S. B., Lussier, J. W., and Hinkle, R. (2005). *Concept Development for Future Domains: A New Method for Knowledge Elicitation*. Tech. rep. 1167. U.S. Army Research Institute for the Behavioral and Social Sciences.

Simon, H. A. (1973). "The Structure of Ill-structured Problems". In: *Artificial Intelligence* 4, pp. 181–201.

Simulation Interoperability Standards Organization (2008). *SISO-STD-007-2008 – Standard for Military Scenario Definition Language (MSDL)*.

Simulation Interoperability Standards Organization (2014a). *SISO-STD-011-2014 – Standard for Coalition Battle Management Language (C-BML) Phase 1, Version 1.0*.

Simulation Interoperability Standards Organization (2014b). *The Command and Control Systems – Simulation Systems Interoperation (C2SIM) Product Development Group (PDG) and Product Support Group (PSG)*.

Simulation Interoperability Standards Organization (2018). *SISO-GUIDE-006-2018 – Guideline on Scenario Development for Simulation Environments*.

Singapogu, S. S., Gupton, K., and Schade, U. (2016). "The Role of Ontology in C2SIM". In: *Proc. 21st International Command and Control Research and Technology Symposium (ICCRTS 2016)*.

Skarpaas, I. and Kristiansen, S. T. (2010). *Simulatortrening for ny praksis: Hvordan simulatortrening kan brukes til å utvikle Hærens operative evne*. Tech. rep. Work Research Institute.

Tolk, A. (2012a). "Integration of M&S Solutions into the Operational Environment". In: *Engineering Principles of Combat Modeling and Distributed Simulation*. Ed. by A. Tolk. Wiley. Chap. 15, pp. 295–327.

Tolk, A. (2012b). "Terms and Application Domains". In: *Engineering Principles of Combat Modeling and Distributed Simulation*. Ed. by A. Tolk. Wiley. Chap. 4, pp. 55–78.

Valaker, S., Hærem, T., and Bakken, B. T. (2018). "Connecting the dots in counterterrorism: The consequences of communication setting for shared situation awareness and team performance". In: *J. Contingencies and Crisis Management.* 26.4, pp. 425–439.

van den Berg, T. W., Huiskamp, W., Siegfried, R., Lloyd, J., Grom, A., and Phillips, R. (2017). "Modelling and Simulation as a Service: Rapid deployment of interoperable and credible simulation environments – an overview of NATO MSG-136". In: *Proc. 2017 Fall Simulation Innovation Workshop*. 17F-SIW-018.

Voss, J. F. and Post, T. A. (1988). "On the Solving of Ill-Structured Problems". In: *The Nature of Expertise*. Ed. by M. T. H. Chi, R. Glaser, and M. J. Farr. Lawrence Erlbaum Associates, Inc., pp. 261–285.

Zook, A., Lee-Urban, S., Riedl, M. O., Holden, H. K., Sottilare, R. A., and Brawner, K. W. (2012). "Automated Scenario Generation: Toward Tailored and Optimized Military Training in Virtual Environments". In: *Proc. International Conference on the Foundations of Digital Games (FDG'12)*. ACM, pp. 164–171.

Challenges and Trends of Data Management for Firefighting in Germany and the Netherlands

Kevin Wesendrup
Westfälische Wilhelms-Universität
Kevin.Wesendrup@uni-muenster.de

Nicola Rupp
Westfälische Wilhelms-Universität
Nicola.Rupp@ercis.uni-muenster.de

Adam Widera
Westfälische Wilhelms-Universität
Adam.Widera@ercis.uni-muenster.de

Bernd Hellingrath
Westfälische Wilhelms-Universität
Bernd.Hellingrath@ercis.uni-muenster.de

ABSTRACT

For successful firefighting, information is key. In this work, a general overview of the current challenges and trends of data management for firefighting in Germany and the Netherlands are examined. This was accomplished by conducting a literature review to find out the current state-of-the-art in research. The results of the literature review are then compared with expert sentiments and gaps between research and practice are revealed. Through the review, six challenge categories are identified: cartographic data harmonization, IS standardization, information gathering from unstructured data, canonical bodies of knowledge, and data-driven firefighting support. The challenges and trends are discussed in the context of Germany and the Netherlands and significant differences are presented. Lastly, the gaps between research and practice are thoroughly analyzed and potentials for future work revealed.

Keywords

Data management, challenges, trends, firefighting

INTRODUCTION

To understand how data management can facilitate successful work practices in the domain of firefighting we must look beyond the for-profit context (Walton et al. 2016 p. 85). The National Institute of Standards and Technology (NIST) released a research roadmap in 2015 which also addresses data management during an emergency event (Grant et al. 2015). In the roadmap, it is concluded that "[t]here are several factors which affect the ability of individual jurisdictions to address the delivery of actionable data to first responders during an event" (Siebert and Venkatasubramanian 2015 p. 139). Additionally, periodicals and research have mainly focused on very specific problems and "literature is significantly limited" (Siebert and Venkatasubramanian 2015 p. 140). Considering these aspects, there is a lack of general overview on how data is managed during a firefighting operation and on what trends and challenges emerged in the past years. It is also unclear, how different jurisdictions adapt to data management innovations. Two countries that adapt very differently to advances in the firefighting sector are Germany and the Netherlands. Germany has problems with adapting innovation (Weidinger et al. 2018 p. 688), especially in rural areas (Müller 2009 p. 81), while the Netherlands have many factors that stimulate high innovation (Nijenhuis and Borninkhof 2015 p. 23). In this article, the current challenges and trends of data management for firefighting in Germany and the Netherlands should be examined (research objective).

To accomplish this overall research objective, the following three sub-objectives have been achieved:

(1) A database and keyword literature search were conducted to identify current pivotal challenges and trends in firefighting which can differ from those that are occurring in practice.
(2) To see how these trends and challenges are adopted in the Netherlands and Germany or whether there are even new trends and challenges in practice, two additional interviews were held with firefighting experts from Germany and the Netherlands.
(3) The literature research was then subjected to a "reality check". The results of the expert interviews

(i.e. the local challenges and trends) were contrasted with the general results from the literature search. Through that, it should be made apparent what trends are popular in the literature but have not made the transition to practice yet and what challenges are currently the focus in each country respectively.

METHODOLOGY

Methodologically, this work is structured in two parts. To identify current trends and challenges, a systematic literature review was carried out. Then, the results of the literature review were juxtaposed with the situation in Germany and the Netherlands by means of expert interviews.

The literature research was based on the systematic literature review process of VOM BROCKE ET AL. (2009). First, a database search was carried out within the Scopus database. Scopus is the biggest database of peer-reviewed titles. To search for literature, the database was first queried with the keyword term *ALL (fire AND fighting AND (trend OR challenge) AND data AND management AND (germany OR netherlands))*. To be able to create an overview of modern challenges and trends, only sources which have been published from 2016 to 2018 were considered initially. The 270 resulting articles (initial hits) were checked for relevance by title evaluation and all but 34 articles were discarded, because they were deemed irrelevant (e.g. medicine, arts etc.). A subsequent abstract evaluation led to 13 relevant hits which were thoroughly analyzed by a full text review. Lastly, the literature research was supported by an internet search of relevant online sources. This was especially crucial for examining what the current state of these trends is, as they were often rapidly changing or were discontinued (e.g. Twitcident: http://www.wis.ewi.tudelft.nl/twitcident/).

The general trends and challenges which have been identified in the literature research were then compared to their local counterparts in Germany and the Netherlands. To do that, two 30- to 45-minute-long interviews were conducted with local experts from the respective country. The interviews were carried out in four steps (Flick 2002 p. 294f.): 1) The interviewer obtained general knowledge of the topic and phrased appropriate questions. 2) The interviewer contacted the appropriate interviewee with the topic. 3) The interview was conducted and recorded. 4) The interview recordings were analyzed, generalized and compared with the results from the literature.

The German expert is head of a department in a big federal firefighting institute and thus a specialist on German firefighting. The department is responsible for crisis management and research and the expert has deep research knowledge, as well as extensive field experience.

The Dutch expert is a firefighter and a CEO of an enterprise that offers data solutions for fire services. He also holds a guest research position at a university in the Netherlands with the research topics emergency response and knowledge management.

THEORETICAL BACKGROUND

To get an understanding on how firefighting works in general and how Germany and the Netherlands operate on a national and local level, some basic processes are introduced to the reader.

Firefighting and Data Management Need

To fight fires a firefighting operation is generally divided into four steps:

(1) Prevention

(2) Preparation

(3) Fire response management

(4) Recovery

This work focuses on the response phase of a firefighting operation (i.e. fire response management).

Due to the complex nature of firefighting, the operators must collect and manage a lot of data throughout these steps. These data can be structured in a lot of different formats (e.g. climate data, time series data, geographic data, textual data). Often the format is proprietary to its private or public organization (Zlatanova et al. 2010). This causes problems when data needs to be harmonized or shared across organizations.

Firefighting in Germany

Who is responsible for firefighting and emergency situations in Germany is organized very differently depending on the local jurisdiction. Responsibility for firefighting is delegated from the state to the cities and counties and thus firefighting institutions are independent from each other and very heterogeneous. Thus, small fires are fought by autonomous fire departments and fires who span multiple regions and cause a lot of damage are fought through a staff organization consisting of multiple local authorities. This tactical-operational staff organization is generally defined in the FwDV 100 ("Feuerwehr-Dienstvorschrift 100") which has been established in Germany in 1999 (Lamers 2016 p. 84). It is important to note that this regulation is not legally binding on a national scale and it is up to the federal states to adapt it in their laws. The defined management staff organization comprises a leader who supervises the staff that is divided into six different areas and additional external consultants (Figure 1). The areas are human resources (S1), location (S2), mission (S3), supply (S4), public relations (S5) and information and communication (S6) (Lamers 2016 p. 85f.).

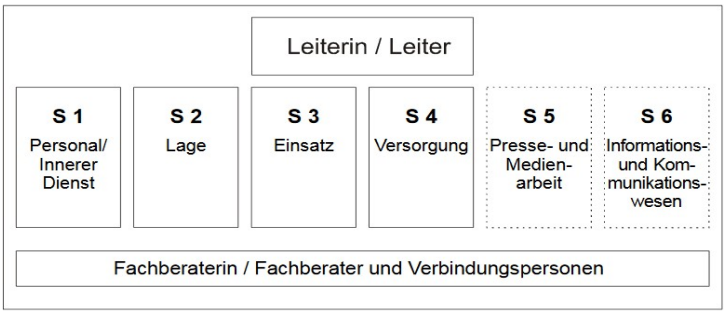


Figure 1. Management staff defined by FwDV 100

Between these specialist areas exists a need for the exchange of information and data, so that they can work together as effective and efficient as possible. LAMERS (2016 p. 88) identified four edges between the different areas, where a close collaboration - and thus a heavy data exchange - is necessary:

(1) S3 and S2 for mission judgment.
(2) S1 and S3 for the reorder of human resources.
(3) S1 and S3 for the management of emergency staging areas.
(4) S4 and S1 for the resupply mission.

Firefighting in the Netherlands

Firefighting in the Netherlands is organized completely different to Germany. The Dutch fire service is a centralized syndicate of all fire brigades of the nation. The brigades are all subordinate to a board of fire chiefs ("Raad van Brandweercommandanten"). In total, the board comprises 25 fire chiefs, one for each safety region ("Veiligheidsregio's") of the Netherlands (Boersma et al. 2012 p. 13). The board has an executive committee, one chairman and six program heads. The program heads are responsible for the following six areas of the national fire service program ("Landelijk Programma Brandweerzorg"):

(1) Risk control and fire-safe living.
(2) Incident control.
(3) Skills and knowledge.
(4) Crisis management.
(5) Information management.
(6) People and business operations.

As many topics are important for each fire department (response times, wide-spread fires in nature or general business management), they are dealt with at a national level. Of course, regional differences are considered (Brandweer Nederland 2015). Work of the programs is carried out in networks and research groups consisting of firefighters under supervision of the central office of the Netherlands Fire Service. Due to this centralized government mode, all safety regions have adopted the so-called netcentric method when working together. This method enables standardized communication between the different partners (Instituut Fysieke Veiligheid 2018). It becomes obvious that the centralized Dutch organization of the fire service is in stark contrast with the federal, decentralized German fire service.

RESULTS

The majority of the results were not exclusive to Germany and the Netherlands. Because of that, the results of the literature are juxtaposed with the results of the expert interviews, which in turn are restrictively focused on the local situation.

Current Challenges

GRASSO ET AL. (2018 p. 625) name "trans-boundary cartographic data harmonization and management for environmental protection and common policies" as big challenges in firefighting operations. The lack of cartographic data is especially critical for widespread fires and access to geographic data is often only possible by accessing different interfaces and thus data of different formats. Because there are different cartographic platforms, so-called geographic information systems (GIS), they are often hard to access in a standardized way, due to their different meta data. Also, integrated into an emergency response system, they often tend to focus only on specific and few parts of the firefighting operation steps, such as command and control (response) or simulation (preparedness).

In city scale scenarios, fires more often occur at places that are more populated (Song et al. 2017 p. 834). Experts are lacking a tool to accurately predict fires, because the explanatory variables that facilitate fires (such as average ground temperature, humidity, etc.) are not collected. This is due to three challenges: 1) the explanatory variables are not recorded in a system, 2) the systems are proprietary, and the data are not stored in an open format and 3) it is unknown how to use these big data to predict fires.

Also, there exist data which are commonly and openly available, but whose potential has yet to be discovered and used. In crisis situations, social media can be a resource of unexplored capabilities. People share their evacuation plans (Chaniotakis et al. 2017) or share information about damages and casualties. This could be used to improve evacuation efforts or to assess incidents by damage, casualties or risk. Again, practitioners are unsure on how to cope with the huge amount of data that is generated by social media sites. Twitter users, for instance, produce over 500 million tweets in a single day and these tweets are polluted with spam, typos and slang (Weiler et al. 2017 p. 329), thus making it hard to extract useful structured data that can be connected to a fire emergency.

Data generation is not a problem anymore as most people carry around GPS ready devices who can put out a lot of geographical information on the go and geographic information technology is more sophisticated than ever. However, consolidating this information into a central knowledge base is still a challenge. GRANELL AND OSTERMANN (2016 p. 231f.) examined volunteered geographic information and geo-social media and concluded that the building of canonical bodies of knowledge has not happened yet, as most studies focus on the challenges and potential of data handling. This stage comprises steps such as merging of data sources, cleaning, annotating, filling missing values and filtering which must be done before an actual analysis of the data at hand can be carried out. Another necessity of canonical bodies is the usage of a shared terminology. For instance, if a dispatch center registers a medium-sized fire it must be known by each participating fire department, what resources to allocate to a fire and therefore it must be known what medium exactly means. An integrated data management for firefighting situations that includes heterogeneous knowledge bases is therefore still out of reach in research, as well as practice.

All challenges are grouped by some general categories and presented in Table 1.

Table 1. Results of the literature review: Challenges

Challenges
Cartographic data harmonization (Grasso et al. 2018)
IS standardization (Granell and Ostermann 2016; Steinhäusler, Friedrich Hällström et al. 2018; Steinhäusler et al. 2018)
Information from unstructured data (Chaniotakis et al. 2017; Weiler et al. 2017)
Creation of canonical bodies of knowledge (Granell and Ostermann 2016)
Creating data-driven firefighting support (Song et al. 2017)

Current Trends

There are some trends that directly tackle previously mentioned challenges. For instance, to harmonize data and establish common policies, a European directive, called information for spatial information in Europe (INSPIRE: https://inspire.ec.europa.eu/), has been setup (Grasso et al. 2018 p. 625). INSPIRE is an initiative of the European parliament and aims at establishing a central GIS. It forces all European countries to 1) standardize their data and

create conform meta data and 2) publish their spatial information over network services. It is in place since 2007 and should be fully implemented in 2021, thus making it at a big current trend in data management for firefighting. GRASSO ET AL. additionally propose a method to design and implement a GIS that fulfills the standards of INSPIRE. The proposed GIS comprises the three major object categories command, land and event which are represented in an INSPIRE-compliant UML model (Grasso et al. 2018 p. 629). For the implementation open source software is used, because it facilitates interoperability through open formats.

Another EU-wide initiative is SAYSO. SAYSO has been initiated in mid of 2017 and should be completed in 2019. It stands for standardization of situational awareness systems to strengthen operations in civil protection and strives to accomplish two deliverables which are relevant to data management. The first deliverable is the specification of open data format standards for crisis management organizations and includes digital map formats, geospatial data, meteorological data, media streaming and many more (Steinhäusler, Friedrich Hällström et al. 2018). The second deliverable is a specification of a multi-stakeholder standardized situational awareness system which is based on requirements of crisis managers, international surveys and several expert meetings (Steinhäusler et al. 2018). When adopted in the future, SAYSO will be a big milestone towards data management standardization in firefighting.

Another trend in the times of big data is the data-driven prediction of fires. Today, researchers have tools of the domain of artificial intelligence at hand which could help to improve prediction. It was mentioned earlier that often data are not recorded sufficiently. Especially data on fire occurrence at the city scale are scarce and site-specific. To tackle this problem, SONG ET AL. (2017) present an econometric model and a random decision forest algorithm which use several variables to predict fires on the scale of Hefei City, a city located in China with a population of almost eight million. The methods work on a reduced set of variables such as elevation, slope and average temperatures. While this study delivered promising results, the research was only done in a case study and its main limitation is that better predictions still rely on an integrated information system (IS) that can deliver a multitude of explanatory variables in real-time (Song et al. 2017 p. 836).

In contrast to data which are not accessible, there is also a lot of data which are available, but whose potential has not been recognized. Through social media, the decision process of people in evacuation situations can be analyzed and used to improve in such conditions. CHANIOTAKIS ET AL. (2017) examined Twitter data from an evacuation in Oroville, USA and created a model that uses historical data to predict the behavior of evacuated people. Twitcident is another online data mining tool that allows to filter tweets related to incidents. The tweets can be filtered by region or topic and can be used to assess damage, casualties and many more. WEILER ET AL. (Weiler et al. 2017 p. 836) proposed an experimental analysis on event detection techniques. Event detection techniques try to extract events (i.e. real-world occurrences that take place in a geographical location over a certain period) out of unstructured data. The analysis should give researchers and practitioners the possibility to choose the best algorithm to extract event data based on their preferred properties such as precision, recall, memory usage or run-time performance.

Another trend tries to answer the challenge of insufficient canonical bodies of consolidated knowledge laid out by GRANELL AND OSTERMANN (Granell and Ostermann 2016 p. 231f.). One example are different definitions of the same term between two different organizations, e.g. our medium-sized fire example from the previous section. To solve this issue, Firebrary (http://www.firebrary.com/) was developed to provide a data dictionary for common terms for the Dutch services. Firebrary uses the SKOS-XL standard to provide open access to people and software (Spaling et al. 2018 p. 122).

Again, all trends are grouped by some general categories and summarized in Table 2.

Table 2. Results of the literature review: Trends

Trends
INSPIRE (Grasso et al. 2018), Digital plan (Weidinger et al. 2018), OpenFireMap, Fireboard
SAYSO (Steinhäusler, Friedrich Hällström et al. 2018; Steinhäusler et al. 2018), Firebrary (Spaling et al. 2018), on-site IS (Weidinger et al. 2018)
Twitter model (Chaniotakis et al. 2017), twitcident, event detection (Weiler et al. 2017)
Firebrary (Spaling et al. 2018)
Econometric model (Song et al. 2017)

Expert Interview: The Situation in Germany

The expert interview with the German expert yielded the following results. If not indicated differently, the source of information is the expert interview.

The recording of the first response in an emergency in Germany is sophisticated. A caller is referred to a control center in which an employee poses structured questions. The answer is put into an IS and subordinate questions are posed until the dispatcher can conclude a so-called alarm key word, a single word that describes type and magnitude of the fire. If agreed, the caller can be located over the mobile network. The gathered information is forwarded to the responsible fire department and resources are allocated depending on the alarm key word (this is defined in the "Alarm- und Ausrückeordnung"). While data of the call is stored in a control center system, the smaller fire departments often have a non-compatible IT infrastructure and thus, the information is printed on an "Alarmdepesche". The "Alarmdepesche" contains information about the route to the operation site, water supply and the caller. For special sites, construction blue prints and maps are stored in paper format at the local fire department. It is rare that a fire department has fully digitized this process, but this is likely to change in the future. A first example is the FIRE application of the department in Berlin where the "Alarmdepesche" is fully substituted by an IS on a tablet (Bäker 2018 p. 479f.). Additionally, the FIRE App is equipped with a hazardous substance database, rescue data sheets and a fire wiki (Bäker 2018 p. 482f.). A similar system has been deployed in Saxony (FwA - "Feuerwehrapp"). The app comprises four modules: a map module with hydrants and water sources, rescue data sheets, a hazardous material information module and a respiratory protection module (Heyne 2018 p. 492f.). More prominent than a digitized "Alarmdepesche" is the automatic transmission of the route into the navigation systems of the fire trucks which is implemented almost everywhere. However, during the actual firefighting almost no IT is used (an exception is the respiratory protection module of the Saxon "Feuerwehrapp"). Afterwards, the operation is documented in an IS.

As identified in the general challenges and trends, GIS are very topical. Due to the independently acting federal states and local fire departments, there are multiple geodatabases. For instance: There exists an ALKIS geo database for Lower Saxony which can be integrated easily with generic interfaces (Dunkel 2018 p. 134), but this is a solution on federal state scale. DUNKEL suggests that all future applications should be encoded in the DIN 14095 standard to increase interoperability on a nation-wide level (Dunkel 2018 p. 140). BERNSDORF identifies four challenges of the usage of geo information for firefighting in Germany: internet connectivity, data actuality, training of executives and operability of these complex systems (Bernsdorf 2018 p. 155f.).

The biggest challenge in the process is the standardization between the local institutions. Due to the independent and autonomous nature of the fire departments, there is a big heterogeneity in IS. HEYNE sees the usage of proprietary systems as the biggest inhibitor of a dissemination of successful software (2018 p. 499). Unfortunately, there is no binding regulation on systems standardization in Germany and a new regulation is costly for the administration of the federal state, due to the "Konnexitätsprinzip", i.e. the state must carry the costs for tasks which it imposes. Control centers of different jurisdictions use proprietary systems. North Rhine-Westphalia alone consists of 52 autonomous control centers. Some federal states have already consolidated their control centers (e.g. Hesse and Bavaria). Additionally, the alarm key words are only standardized within a county. A country-wide glossary or general semantics do not exist. This is especially critical for fires which span multiple regions.

For such fires, a crisis staff must be established and here, the problem of standardization is even more critical. The go-to data management device is still e-mail and telephone communication, as no integrated software solution is implemented. There are some efforts to offer central data management tools. North Rhine-Westphalia has a database where resources such as water reserves are stored ("Informationssystem Gefahrenabwehr NRW"). There is also an EU wide project for the standardization of situational awareness tools (project SAYSO, mentioned earlier). Still, crisis management is relying on traditional methods for communication which partially exists since multiple decades (e.g. paper message and radio). Rarely, more advanced technologies such as fax or scans are used. The whole procedure is slow and full of misunderstandings.

All in all, politics, federalism and the decentralization of responsibilities to the local authorities are the main reasons for the non-standardization of data management for firefighting in Germany and this is one of the biggest challenges.

Expert Interview: The Situation in the Netherlands

Because of their safety-regional structure, the Netherlands are not as federal as Germany and thus systems standardization is much less of a problem. The safety regions are not centrally governed; their geographical borders are defined by law, but their mode of operation is autonomous. Still, there is a nationally standardized radio communication system and a central national dispatch system, which are standardized even across the autonomous safety regions. Only some systems, such as human resource management systems, are procured locally.

The expert sees the biggest challenge in data management in the qualification of the fire fighters. When fire fighters are employed, they are tested on practical skills, rarely are they tested on IT competence or trained while on the job. Of course, this stems from firefighting requiring a whole different set of base qualifications.

Another challenge is the inertia of the fire service as a governmental institution. For the innovation of legacy information or data management technologies within the institutions, a complex procurement process needs to be initiated because investments are often very big. Due to the complexity of the procurement that is often subsidized with only small budgets, innovation is very tedious.

It is notable that while IS standardization is a smaller issue than in Germany, the creation of a canonical body of knowledge and shared semantics is very important in the Netherlands. To allow effective communication between different firefighting departments, there must be a taxonomy of firefighting terminology and information architecture of the IT systems must be improved. A notable endeavor to do this is Firebrary, a data dictionary for common terms for the Dutch service which was introduced earlier.

Also, the expert mentions that "the road to AI leads through IA [information architecture]". This means that first, the data in the systems must be harmonized, before it can be used for artificial intelligence, due to its data-driven nature. The Netherlands also employed first trials with artificial intelligence. While artificial intelligence is not used for predicting fires, it showed very promising results when fighting a fire and looking for similar environments or buildings to gather helpful information. Another data-driven firefighting support tool is RESC Info Insight that allows to combine forensic research data, internal statistical data and publicly available data to gain additional insights (https://netage.nl/resc-info-insight/).

All in all, the Netherlands are also concerned with some more traditional challenges such as building of canonical bodies of knowledge, as well as more advanced technologies, such as data-driven firefighting support.

DISCUSSION

To get a concluding overview on which challenges were identified and which trends are answering these challenges, Table 3. **Challenges and trends of data management in firefighting**

Challenge	Trend
Literature Review / International	
Challenge	**Trend**
Literature Review / International	
Cartographic data harmonization (Grasso et al. 2018)	INSPIRE (Grasso et al. 2018), Digital plan (Weidinger et al. 2018), OpenFireMap, Fireboard
IS standardization (Granell and Ostermann 2016; Steinhäusler, Friedrich Hällström et al. 2018; Steinhäusler et al. 2018)	SAYSO (Steinhäusler, Friedrich Hällström et al. 2018; Steinhäusler et al. 2018), Firebrary (Spaling et al. 2018), on-site IS (Weidinger et al. 2018)
Information from unstructured data (Chaniotakis et al. 2017; Weiler et al. 2017)	Twitter model (Chaniotakis et al. 2017), twitcident, event detection (Weiler et al. 2017)
Creation of canonical bodies of knowledge (Granell and Ostermann 2016)	Firebrary (Spaling et al. 2018)
Creating data-driven firefighting support (Song et al. 2017)	Econometric model (Song et al. 2017)
Germany	
Cartographic data harmonization (Bernsdorf 2018)	Feuerwehrapp (Heyne 2018), ALKIS (Dunkel 2018)
IS standardization (Heyne 2018)	FIRE App (Bäker 2018), Feuerwehrapp (Heyne 2018), SAYSO
Netherlands	
Lack of IT qualifications	none
Governmental innovation inertia	none
Canonical bodies of knowledge	Firebrary (Spaling et al. 2018)
Data-driven firefighting support	Artificial intelligence for similar fire environments, RESC Info Insight

Cartographic data harmonization (Grasso et al. 2018)	INSPIRE (Grasso et al. 2018), Digital plan (Weidinger et al. 2018), OpenFireMap, Fireboard
IS standardization (Granell and Ostermann 2016; Steinhäusler, Friedrich Hällström et al. 2018; Steinhäusler et al. 2018)	SAYSO (Steinhäusler, Friedrich Hällström et al. 2018; Steinhäusler et al. 2018), Firebrary (Spaling et al. 2018), on-site IS (Weidinger et al. 2018)
Information from unstructured data (Chaniotakis et al. 2017; Weiler et al. 2017)	Twitter model (Chaniotakis et al. 2017), twitcident, event detection (Weiler et al. 2017)
Creation of canonical bodies of knowledge (Granell and Ostermann 2016)	Firebrary (Spaling et al. 2018)
Creating data-driven firefighting support (Song et al. 2017)	Econometric model (Song et al. 2017)
Germany	
Cartographic data harmonization (Bernsdorf 2018)	Feuerwehrapp (Heyne 2018), ALKIS (Dunkel 2018)
IS standardization (Heyne 2018)	FIRE App (Bäker 2018), Feuerwehrapp (Heyne 2018), SAYSO
Netherlands	
Lack of IT qualifications	none
Governmental innovation inertia	none
Canonical bodies of knowledge	Firebrary (Spaling et al. 2018)
Data-driven firefighting support	Artificial intelligence for similar fire environments, RESC Info Insight

Table 3 is presented. The table visualizes the results of the previous sections. To do that in a simple manner, categories of challenges were formed and one or multiple challenges were grouped by these categories.

The results from the literature review (international) were diverse and range from more traditional challenges,

Table 3. Challenges and trends of data management in firefighting

such as geo-data and IS harmonization and standardization to more innovative trends. When looking at the more innovative trends such as information gathering from twitter data or econometric fire prediction, it becomes apparent that these were not implemented through persisting and sustainable solutions, but through pioneering case study research. This is a small hint that these trends might not have made the transition to practice yet. On the plus side, there is no international category of challenges which is not addressed by at least one trend.

On the German side, challenges and trends look completely different. Information gathering from unstructured data and data-driven firefighting support are not addressed at all. The more traditional topics such as cartographic data and IS standardization are currently under heavy implementation. Because these topics take a lot of effort and are often a prerequisite for more advanced technology, current practice in Germany will probably take some time to fully adopt them. Due to Germany's federal nature, it will take some more years, before the more pioneering technologies will be integrated.

In the Netherlands, cartographic data and IS standardization are not a current challenge, because the Netherlands employ an integrated IT infrastructure within their safety regions. Canonical bodies of knowledge and a taxonomy are very important and already tackled by some approaches. The Netherlands additionally touched some areas which are currently unreachable for Germany. These comprise data-driven approaches. The Netherlands have also some more advanced challenges, that have not been answered, such as lack of qualifications and governmental innovation inertia. These two categories were not even recognized by the literature review. This may potentially be, because the used key words were focused on information systems research, while the two problems should be viewed through the lens of organization science.

CONCLUSION

Some unique revelations could be made through the combination of a literature review and interviews with local firefighting experts.

All in all, one can say that most of the current challenges are answered by at least one trend. Still, the situation of Germany and the Netherlands could not look more different, which is an interesting finding as both countries are alike in many other areas. While the former is determined by its federal political system, it cannot yet adopt newer technologies, because the basis of IS standardization is missing. It will take some more years (or even decades) for Germany to adopt newer trends and even then, the solutions will be pushed by single local fire departments instead of being established on a national scale. These phenomena are almost non-existent in the Netherlands, due to their centrally regimented safety regions, and more progressive trends emerged in the last couple of years. It is notable that challenges of the Netherlands are not only limited to the domain of information systems, but also organization science, and thus an interdisciplinary approach, that cannot be achieved by technological advances alone, is required to solve them.

For further research, some improvements can be made. The keywords could be extended to conduct an exhaustive literature review in future work. The authors also suggest, that the scope of the literature review should be extended to include literature from organization science which was not possible with the used key words. Additionally, it must be questioned whether a structured literature is the right means to identify (local) trends and challenges. Because much information is intangible and not accessible in research databases, more experts must be interviewed to get a more comprehensive and objective overview. This also increase the objectivity of the expert judgements. Additionally, the work is very descriptive, a structured comparison of countries could lead to learnings one country could gain from another country, thus making the research more prescriptive.

These limitations therefore address some gaps that must be bridged. For future research the authors recommend following research agenda which is concluded from the results and limitations:

(1) Standardized IT infrastructure in Germany.

(2) Lack of qualifications in the Netherlands.

(3) Governmental innovation inertia in the Netherlands.

(4) Practical applicability of information retrieval from unstructured data.

(5) Prescriptive analysis of practices to facilitate the adaption to challenges and adoption to trends.

To determine what happens with data management in the near future is dependent on how technology advances further and even more dependent on how the political systems in Germany and the Netherlands will facilitate innovation in the area of firefighting. One thing is sure, for the coming decades it will be a topic of high interest and constant change.

REFERENCES

Bäker, L. (2018). "Digitale Führungsunterstützung - Tablets an der Einsatzstelle - Teil 1." *Tagungsband der 65. Jahresfachtagung*, Vereinigung zur Förderung des Deutschen Brandschutzes e.V., Münster, 479–489.

Bernsdorf, B. (2018). "Geodateninfrastrukturen im Feuerwehrwesen - Grundlagen und Herausforderungen von Geofachdaten-Pools der Feuerwehren." *Tagungsband der 65. Jahresfachtagung*, Vereinigung zur Förderung des Deutschen Brandschutzes e.V., Münster, 145–160.

Boersma, K., Wagenaar, P., and Wolbers, J. (2012). "Negotiating the 'Trading Zone'. Creating a Shared Information Infrastructure in the Dutch Public Safety Sector." *Journal of Homeland Security and Emergency Management*, 9(2), 1–25.

Brandweer Nederland. (2015). "Strong together - Safe together." <https://www.brandweer.nl/media/1623/fld_hartziel-eng.pdf> (Dec. 23, 2018).

vom Brocke, J., Simons, A., Niehaves, B., Riemer, K., Plattfaut, R., and Cleven, A. (2009). "Reconstructing the Giant: On the Importance of Rigour in Documenting the Literature Search Process." *ECIS*, 9, 2206–2217.

Chaniotakis, E., Antoniou, C., and Pereira, F. C. (2017). "Enhancing resilience to disasters using social media." *5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems, MT-ITS 2017 - Proceedings*, 699–703.

Dunkel, S. (2018). "Geoinformation, Quo vadis?" *Tagungsband der 65. Jahresfachtagung*, Vereinigung zur Förderung des Deutschen Brandschutzes e.V., Münster, 133–144.

Flick, U. (2002). *Qualitative Sozialforschung. Eine Einführung*. rowohlts enzyklopädie, Reinbek.

Granell, C., and Ostermann, F. O. (2016). "Beyond data collection: Objectives and methods of research using VGI and geo-social media for disaster management." *Computers, Environment and Urban Systems*, 59,

231–243.

Grant, C., Hamins, A., Bryner, N., Jones, A., and Koepke, G. (2015). *Research roadmap for smart fire fighting*. US Department of Commerce, National Institute of Standards and Technology.

Grasso, N., Lingua, A. M., Musci, M. A., Noardo, F., and Piras, M. (2018). "An INSPIRE-compliant open-source GIS for fire-fighting management." *Natural Hazards*, 90(2), 623–637.

Heyne, G. (2018). "Digitale Führungsunterstützung - Tablets an der Einsatzstelle - Teil 2." *Tagungsband der 65. Jahresfachtagung*, Vereinigung zur Förderung des Deutschen Brandschutzes e.V., Münster, 491–500.

Instituut Fysieke Veiligheid. (2018). "Netcentrisch Werken." <https://www.ifv.nl/advieseninnovatie/Paginas/Netcentrisch-Werken.aspx> (Dec. 23, 2018).

Lamers, C. (2016). *Stabsarbeit im Bevölkerungsschutz*. Stumpf+ Kossendey, Edewecht.

Müller, J. (2009). "Zukunft der Feuerwehr - Feuerwehr der Zukunft im ländlichen Raum." Bergische Universität Wuppertal.

Nijenhuis, K., and Borninkhof, E. (2015). "Innovatie binnen de brandweer in Nederland Management Samenvatting." <https://www.ifv.nl/nieuws/Documents/Innovatief-gedrag-in-brandweer-nederland.pdf> (Mar. 16, 2019).

Siebert, P., and Venkatasubramanian, N. (2015). "Use of Data During an Emergency Event." *Research roadmap for smart fire fighting*, US Department of Commerce, National Institute of Standards and Technology, 139–159.

Song, C., Kwan, M. P., Song, W., and Zhu, J. (2017). "A Comparison between spatial econometric models and random forest for modeling fire occurrence." *Sustainability (Switzerland)*, 9(5), 1–21.

Spaling, G., Peters, R., and Wilson, F. (2018). "Improving Crisis Response by Interconnecting Data Worlds." *Electronic Journal of e-Government*, 16(2), 119–126.

Steinhäusler, Friedrich Hällström, M., Ahlsen, M., and Burkow, H. M. (2018). "Deliverable D3.1 - Input- and Output Data Formats used by EU Crisis Response Organisations." *SAYSO - Standardisation of Situational Awareness Systems to Strengthen Operations in Civil Protection*, SAYSO Consortium, Bonn, 1–32.

Steinhäusler, F., Ahlsen, M., Chasiotis, I., Greenstein, S., Hällström, M., McCall, R., Müller, S., and Zaitseva, L. (2018). "Deliverable D3.3 - Advanced MSSAS Specifications V1 (internal)." *SAYSO - Standardisation of Situational Awareness Systems to Strengthen Operations in Civil Protection*, SAYSO Consortium, Bonn, 1–108.

Walton, R., Mays, R. E., and Haselkorn, M. (2016). "Enacting Humanitarian Culture: How Technical Communication Facilitates Successful Humanitarian Work Enacting Humanitarian Culture." *Technical Communication: Journal for the Society of Technical Communication*, 63(2), 85–100.

Weidinger, J., Schlauderer, S., and Overhage, S. (2018). "Is the Frontier Shifting into the Right Direction? A Qualitative Analysis of Acceptance Factors for Novel Firefighter Information Technologies." *Information Systems Frontiers*, 20(4), 669–692.

Weiler, A., Grossniklaus, M., and Scholl, M. H. (2017). "Survey and experimental analysis of event detection techniques for twitter." *Computer Journal*, 60(3), 329–346.

Zlatanova, S., Dilo, A., de Vries, M., and Fichtinger, A. (2010). "Models of Dynamic Data for Emergency Response: A Comparative Study." *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 38(01).

The Influence of Swift Trust on Virtual Team's Sensemaking in Crisis: A Research Model

Xiodan Yu
University of International Business and Economics (China)
xyu@uibe.edu.cn

Deepak Khazanchi
University of Nebraska at Omaha (USA)
CIEM, University of Agder (Norway)
khazanchi@unomaha.edu

ABSTRACT

Virtual teams are an important form of collaboration, especially in the context of transboundary crises. Achieving team effectiveness through good sensemaking is key to virtual teams' success in responding to crisis. However, there is still a lack of understanding about the relationship of this sensemaking in a virtual team during crisis to the virtual team's development of swift trust. Adapting from a model of sensemaking, in this paper, we propose a research model to describe the relationships among swift trust, sensemaking and virtual team performance in the context of virtual teams during crisis.

Keywords

Virtual teams, crisis, sensemaking theory, swift trust, team performance.

INTRODUCTION

Organizations are constantly adapting to contextual changes (Albu & Wehmeier, 2014). One such "change" happens when organizations face crises. Organizational crisis are events that represent the most extreme and severe situations and are characterized in terms of their high risk, low probability, high uncertainty, and time pressure (Weick, 1988). Ineffective responses to a crisis can threaten organizational identity and potentially damage the reputation of the organization (Harden & Fulop, 2015). For example, Equifax a consumer credit reporting agency, faced a major cybersecurity crises in 2017, when it discovered and reported that over 143 million U.S. customers' personally identifiable information (PII) was breached (Agnes, 2017). Agnes (2017) summarized the response to this crisis by Equifax as follows: "While their messaging was weak coming out, their strategy of communication dissemination has since been quite strong." She adds "They (Equifax) will inevitably be defined by this incident, whether they like it or not. And yes, they will also be defined by the way they choose to respond."

Crisis research, in particular, organizational crisis research has burgeoned over the past decade (Jong, Dückers, & Velden, 2016; Paraskevas, 2006; Sauer, Felsing, Franke, & Rüttinger, 2007; Stachowski, Kaplan, & Waller, 2009). In particular, **sensemaking**, a process oriented construct, has been used as an effective theoretical lens for capturing the underlying path to successful crisis management. However, most studies in this line of research either focus on identifying the constituting elements of sensemaking (e.g. Hamm et al., 2015) or treat sensemaking as an endogenous factor to organizational or teams' performance in crisis (e.g. Higgins & Freedman, 2013).

Therefore, in this paper we attempt to fill the aforementioned theoretical gap by identifying "swift trust" as an important exogenous antecedent of sensemaking. We conceptually begin the exploration of the following research questions: How does swift trust influence sensemaking and its components? Can sensemaking in turn influence virtual team performance? We propose a research model for studying how sensemaking and swift trust influence virtual team performance during organizational crisis. Virtual teams generally have diverse

members with different skills and status. Prior research has found that under such a circumstance, virtual team members develop a priori "swift trust" (Meyerson, Weick, & Kramer, 1996). Swift trust is a key condition of virtual team members' sharing of information that is essential to virtual teams' sensemaking. Swift trust is an indicator of team capability and plays a key role in facilitating sensemaking (Waller, Lei, & Pratten, 2014).

CONCEPTUAL FOUNDATIONS

Sensemaking theory

Sensemaking *is the process through which individuals and groups attempt to explain novel, unexpected, or confusing events* (Weick, Sutcliffe, & Obstfeld, 2005). Sensemaking usually occurs at the early stages of a crisis (Boin et al., 2014). Key activities associated with sensemaking include information gathering, information dissemination, information sharing, and interactions among members (Thomas, Clark, & Gioia, 1993). Weick suggested three categories of sensemaking tasks: perceptions, interpretations, and actions. Sensemaking is one essential behavioral indicator of teams that begin actively engaging in cognizing, understanding, interpreting, and sharing among team members (Sackman, 1991; Weick, 1988). During sensemaking, individuals may develop different interpretations of the situation (Maitlis, 2005; Reissner, 2011; Weick & Roberts, 1993) .

Research that discussed sensemaking during organizational crisis has primarily focused on the topics of leader communication strategy (Boin & Renaud, 2013; Dixon, Weeks, Boland, & Perelli, 2017; Salicru, 2017), organizational transparency (Albu et al., 2014), individual's sensemaking of risk (Wall, 2014), inter-organizational cooperation styles (Boin et al., 2014), and reducing ambiguity in organizations (Burke et al., 2006). Generally, researchers agree that during crisis, organizations have to balance between the effort of collecting a complete and accurate information set and the choice of comprehending the gathered information in a timely manner.

A concept that is important for understanding the notion of sensemaking is *ambiguity*. Ambiguity is a distinct characteristic of all crises. A critical task for people involved in sensemaking during crisis is to reduce such ambiguity by better comprehending the crisis (Stieglitz, Mirbabaie, & Milde, 2018). Caroll (2015) proposes three categories of ambiguity during crisis: fundamental ambiguity, causal ambiguity, and role ambiguity. Fundamental ambiguity refers to the situation when no one is capable of putting a label or category on the crisis. Subjects experience causal ambiguity when they know what is going on but struggling to determine the causal attribution of the crisis. Role ambiguity describes the individuals who are accountable for specific tasks during the crisis. The outcome of sensemaking should be a shared and accurate understanding of ambiguity across these categories during a crisis.

Another important concept for sensemaking is "relationship." During crisis, organizational leaders have to manage both the internal relationships within organizations and the external relationships with stakeholders and the public. Crises can lead to a high degree of uncertainty and anxiety. Negative feelings and emotions, such as fear and anger, can cause irrational decisions with unintended consequences (Elfenbein, 2007). Environmental changes can also lead to cognitive disorders, confusion, anxiety and nervousness (Mckinley & Scherer, 2000). The distrust of organizational leaders' competence can also affect an individual's understanding of crises (Yin & Jing, 2014). In addition to the internal relationship, external relationships with the public and stakeholders are also very important. Research has shown that following a crisis, a transparent communication strategy can enhance the credibility and trustworthiness of a company in crisis (Albu et al., 2014).

Swift trust

Compared to co-located teams or traditional face-to-face teams, ICT enabled virtual teams experience more challenging issues when working together. In particular, building trust among members is one of the most significant challenges for virtual teams. For geographic, temporal, and physically dispersed teams, trust is essential for team members to work together toward their goals (Jarvenpaa, Knoll, & Leidner, 1998). Due to the loss of body language and non-verbal cues, virtual teams' trust development is difficult when most of the collaboration and coordination rely on ICT.

Prior studies have found that effective virtual teams formed "swift trust" when teams are temporal and were working a time-constraint (Meyerson et al., 1996). Swift trust was found to be a special kind of trust unique to virtual teams when members with little to no co-working experience worked together temporally (Meyerson et al., 1996; Suzanne & Weisband, 1997). Distinct from social-interaction based trust, swift trust is not cognitive or affective and occurs in the early stage of team formation (Suzanne et al., 1997).

Swift trust is especially useful for understanding effective team operations during crisis (Curnin, Owen, Paton,

Trist, & Parsons, 2015). Prior studies have revealed that the establishment of swift trust in virtual teams cannot only affect how teams communicate and interact with each other, but also can affect how well the team accomplishes its goals (Henttonen & Blomqvist, 2005; Kanawattanachai & Yoo, 2002). In addition, swift trust is important for virtual team members to engage in sustainable cooperation under ambiguous situations (Hyllengren, Larsson, Fors, Sjöberg, Eid, & Olsen, 2011; White, Plotnick, Addams-Moring, Turoff, & Hiltz, 2008). Researchers have found that teams in crisis are more inclined to establish swift trust that accelerates the team process and task accomplishments.

RESEARCH MODEL

In the context of the use of virtual teams during crisis, Figure 1 presents our research model depicting the hypothesized relationships among individual's swift trust, sensemaking and team performance. In particularly, we adopted three sub-dimensions of sensemaking proposed by Basu and Palazzo (Basu & Palazzo, 2008), i.e. cognitive development, linguistic development, and conative development.

With regard to operationalization of sensemaking, the study conducted by Basu and Palazzo (Basu et al., 2008) offers a viable approach. Basu and Palazzo propose three dimensions of sensemaking, i.e. *cognitive*, *linguistic* and *conative* (Basu et al., 2008). According to them, *cognitive* refers to thinking about the organization's relationships with its stakeholders and possible impact on key relationships; *linguistic* involves justifying, communicating and sharing the rationale of particular crisis response actions; and *conative* involves the actual behavioral posture the organization adopts and the commitment and consistency it shows with the activities conducted. Contrary to other studies of crises that predominantly focus on the role of the external environment in an institutions' reaction to crisis, Basu and Palazzo assert that attention to the institutions' internal cognitive and linguistic processes is also important. They argue that these are key processes and can affect how institutions view their relationships with stakeholders during crisis and how the institutions may engage during crisis response. Adapting Basu and Palazzo's (Basu et al., 2008) model to the team level, we propose studying virtual teams' reaction during crisis by going beyond a content analysis driven-approach. Thus, based on prior understanding of sensemaking, we assert that a particular **cognitive process (i.e., the team's interpersonal process), two linguistic processes (i.e. team knowledge sharing, team mutual awareness), and two conative processes (i.e. process conflict, shared temporal cognition)** mediate the relationship between swift trust development and virtual team performance (refer Figure 1).

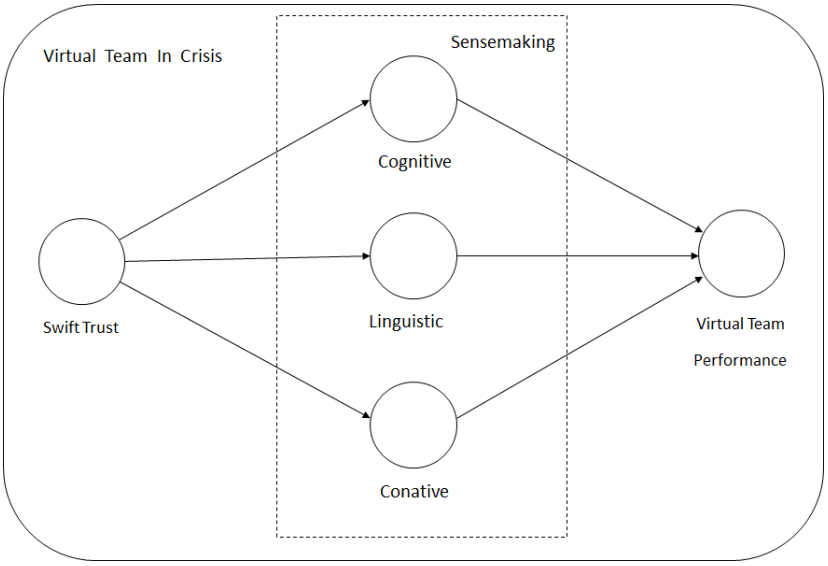


Figure 1. Influence of Swift Trust on Virtual Team Performance through Sensemaking

DISCUSSION AND IMPLICATIONS

Crisis can lead to severe breakdowns of organizational norms that result in ambiguity and negative feelings among stakeholders, public, as well as internal employees (King, 2002). One challenge of virtual teams in crisis is to develop shared understanding, i.e. cognitive development, of the consequences of crisis on organization's internal and external relationships (Basu et al., 2008). Establishing swift trust enhances knowledge sharing and increases

frequency of interactions, which lead to greater level of cognitive development in virtual teams. In addition, in the virtual team context where effective leadership can be significantly different from collocated teams, swift trust contributes to cognitive sharing among team members (Al-Ani, Horspool, & Bligh, 2011). Therefore, as illustrated in Figure 1, **swift trust promotes the formation of cognitive structure**, which allows work in virtual teams to be coordinated and synchronized (Curnin et al., 2015).

Swift trust is critical for promoting free information flow and knowledge exchange in virtual teams. Prior research has shown that in virtual teams' context, members are more likely to build situational attributions against perceived negative behaviors of other members than collocated teams (Cramton, Orvis, & Wilson, 2007). One study found that during crisis, virtual teams' communication frequency dropped significantly resulting from the seriousness of the threat and time urgency (Kamphuis, Gaillard, & Vogelaar, 2011). Though during crisis, virtual teams may reduce level of social interaction and learning about one another's preferences and behaviors, swift trust promotes free interaction among team members in a short period of time (Radcliffe & Schniederjans, 2003). Further, based on free conversation, our research model incorporates the notion that **trust makes the team members more willing to interact and communicate both formally and informally** (Fischbacher et al., 2014).

Swift trust ensures commitment and consistency as virtual teams conduct activities in crisis, i.e. conative, dimension of sensemaking (Basu et al., 2008). Virtual team enter the conative stage when they start action following decision-making (Hazel & Kang, 2018). Researchers have shown a positive correlation between organization strategy consistency and organization performance (e.g., Bourgeois, 1980). Swift trust plays an important role by speeding up the decision-making process, eliminating obstacles in the process of knowledge sharing, promoting a win-win cooperation within the team, enhancing communication and cooperation among team members, and achieving consistency in problem solving strategies (Higgins et al., 2013).

Sense making can help resolve ambiguity, **facilitate information sharing and mitigate negative feelings such as stress and fear during crisis.** We expect that this generalized relationship will also hold true in the virtual team context. In complex situations, such as crises, teams cannot rely on intuitive decisions, which can be very risky without review and evaluation (Higgins et al., 2013). A good cognitive development of the crisis can enhance virtual teams' understanding of the full complexity of the crisis, forming a more thorough and correct picture (Waller et al., 2014).

Communication and transparency are two most discussed topics in crisis management. To achieve a better performance, effective and timely communication is critical (Cheng & Macaulay, 2014). With linguistic development, i.e. clear communication and appropriate information disclosure, virtual-teams are able to promote shared understanding the crisis and the rationale for the team's actions during crisis. Such shared understanding helps enhance team effectiveness and adaptability in crisis (Nemiro, Beyerlein, Bradley, & Beyerlein, 2008). Communication is also critical to distributed-team success in that the condition through which divergent members' skills and knowledge, and cognitive style can be integrated and leveraged to achieve synergies (Kroenke, 2011). Through efficient communication, virtual team members are able to build strong ties which was suggest to influence members' comfortableness of working together (Benetytė & Jatuliavičienė, 2014). Effective communication can facilitate the development of a conversational space where all perspectives are heard and discussed, all possibilities are explored (Benetytė et al., 2014; Harden et al., 2015; Harush, Glikson, Nouri, & Shokef, 2013).

CONCLUSION

The main objective of this paper is to propose a research model based on prior literature that allows us to examine the relationships between virtual team swift trust, sensemaking, and team performance in the context of organizational crisis. Specifically, we assert that the establishment of swift trust has a positive influence on the three sub-dimensions of sensemaking - cognitive, linguistic, and conative. Overall, our research contributes to both crisis and IS literature by offering a research model depicting the relationships among swift trust, sensemaking, and team performance. We are currently in the process of empirically testing the proposed research model.

ACKNOWLEDGEMENT

This work was partially supported by National Natural Science Foundation of China (Grant No. 71501044) and the Fundamental Research Funds for the Central Universities in UIBE (Grant No: 16YQ07).

REFERENCES

Al-Ani, B., Horspool, A., & Bligh, M. C. (2011). Collaborating with 'virtual strangers': Towards developing a framework for leadership in distributed teams. Leadership, 7(3), 219–249.

Albu, O. B., & Wehmeier, S. (2014). Organizational Transparency and Sense-Making: The Case of Northern Rock. Journal of Public Relations Research, 26(2), 117-133.

Agnes, M. (2017). Equifax's Crisis Response Strategy: What You Need To Know. Forbes, https://www.forbes.com/sites/melissaagnes/2017/09/10/equifaxs-crisis-response-strategy-what-you-need-to-know/#10dc69dc1728, Retreived January 2st, 2019.

Basu, K., & Palazzo, G. (2008). Corporate Social Responsibility: A Process Model of Sensemaking. Academy of Management Review, 33(1), 122-136.

Benetytė, D., & Jatuliavičienė, G. (2014). Building and sustaining trust in virtual teams within organizational context. Region Formation & Development Studies, 10(2).

Birdie, A. K., & Jain, M. (2016). Perceived Organizational Climate & Interpersonal Trust among Virtual Workers. ndian Journal Of Industrial Relations, 51(4), 609-619.

Boin, A., Busuioc, M., & Groenleer, M. (2014). Building European Union capacity to manage transboundary crises: Network or lead-agency model? Regulation & Governance, 8(4), 418-436.

Boin, A., & Renaud, C. (2013). Orchestrating Joint Sensemaking Across Government Levels: Challenges and Requirements for Crisis Leadership. Journal Of Leadership Studies, 7(3), 41-46.

Bourgeois, L. J. (1980). Performance and Consensus. Strategic Management Journal, 1(3), 227-248.

Broekema, W., Kleef, D., & Steen, T. (2017). What Factors Drive Organizational Learning From Crisis? Insights From the Dutch Food Safety Services' Response to Four Veterinary Crises. Journal Of Contingencies & Crisis Management, 25(4), 326-340.

Brower, H. H., Lester, S. W., Korsgaard, M. A., & Dineen, B. R. (2009). A closer look at trust between managers and subordinates: Understanding the effects of both trusting and being trusted on subordinate outcomes. Journal of Management 35(2), 327-347.

Bundy, J., & Pfarrer, M. D. (2015). A burden of responsibility: the role of social approval at the onset of a crisis. Academy of Management Review, 40(3), 345-369.

Burke, C. S., Stagl, K. C., Salas, E., Pierce, L., & Kendall, D. (2006). Understanding team adaptation: A conceptual analysis and model. Journal of Applied Psychology, 91(6), 1189-1207.

Carroll, J. S. (2015). Making Sense of Ambiguity through Dialogue and Collaborative Action. Journal Of Contingencies & Crisis Management, 23(2), 59-65.

Cheng, X., & Macaulay, L. (2014). Exploring Individual Trust Factors in Computer Mediated Group Collaboration: A Case Study Approach. Group Decision & Negotiation, 23(3), 533-560.

Cramton, C. D., Orvis, K. L., & Wilson, J. M. (2007). Situation invisibility and attribution in distributed collaborations. Journal of Management, 33(4), 525-546.

Curnin, S., Owen, C., Paton, D., Trist, C., & Parsons, D. (2015). Role Clarity, Swift Trust and Multi-Agency Coordination. Journal of Contingencies & Crisis Management, 23(1), 29–35.

Dixon, D. P., Weeks, M., Boland, R., & Perelli, S. (2017). Making Sense When It Matters Most: An Exploratory Study of Leadership In Extremis. ournal Of Leadership & Organizational Studies, 24(3), 294-317.

Elfenbein, H. A. (2007). Emotion in organizations: A review and theoretical integration [J]. Academy of Management Annals, 1, 315–386.

Espinosa, J. A., Nan, N., & Carmel, E. (2015). Temporal Distance, Communication Patterns, and Task Performance in Teams. Journal Of Management Information Systems, 32(1), 151-191.

FÂRTE, G. (2013). Emotion Management in Crisis Situations. Journal the Seminar of Discursive Logic, Argumentation Theory & Rhetoric, 11(2), 59-70.

Fischbacher, S., D., & Fischbacher, S., M. (2014). What Lies Beneath? The Role of Informal and Hidden Networks in the Management of Crises. Financial Accountability & Management, 30(3), 259-278.

Geneviève, D., Sébastien, T., Simon, B., & Vincent, R. (2010). Team Performance and Adaptability in Crisis Management: A comparison of cross-functional and functional teams. Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Germain, M., & McGuire, D. (2014). The Role of Swift Trust in Virtual Teams and Implications for Human Resource Development. Advances In Developing Human Resources, 16(3), 356-370.

Gutwin, C., & Greenberg, S. (2002). A descriptive framework of workspace awareness for real-time groupware. Computer Supported Cooperative Work, 11, 411-446.

Hamm, S.W., Jung, M. J., & Wang, C. (2015). Making Sense of One Dollar CEO Salaries. Contemporary Accounting Research, 32(3), pp.941-972.

Harden, H., & Fulop, L. (2015). The Challenges of a Relational Leadership and the Implications for Efficacious Decision-Making in Healthcare. Asia Pacific Journal Of Health Management, 10(3), SI51-SI62.

Harush, R., Glikson, E., Nouri, R., & Shokef, E. (2013). Going global:developing management students' cultural intelligence and global identity in culturally diverse virtual teams. Academy of Management Learning & Education, 12.

Hazel, D., & Kang, J. (2018). The Contributions of Perceived CSR Information Substantiality Toward Consumers' Cognitive, Affective, and Conative Responses:The Hierarchy of Effects Model Approach. Clothing and Textiles Research Journal, 36(2), 62-77.

Henttonen, K., & Blomqvist, K. (2005). Managing distance in a global virtual team: the evolution of trust through technology-mediated relational communication. Strategic Change, 14(2), 107-119.

Higgins, G., & Freedman, J. (2013). Improving decision making in crisis. Journal Of Business Continuity & Emergency Planning, 7(1), 65-76.

Hill II, M. A. (2013). Analysis of Distributed-Team Supportive-Technology. Proceedings Of The Northeast Business & Economics Association, 95-99.

Hinds, P. J., & Bailey, D. E. (2003). Out of sight, out of sync: Understanding conflict in distributed teams. Organization Science, 14(6), 615-632.

Hyllengren, P., Larsson, G., Fors, M., Sjöberg, M., Eid, J., & Olsen, O. K. (2011). Swift trust in leaders in temporary military groups. Team Performance Management, 17(7/8), 354-368.

James, E. H., Wooten, L. P., & Dushek, K. (2011). Crisis management: Informing a new leadership research agenda. Academy of Management Annals, 5, 455-493.

Jarvenpaa, S. L., Knoll, K., & Leidner, D. E. (1998). Is anybody out there? Antecedents of trust in global virtual teams. Journal of Management Information Systems, 14(29-64).

Jin, Y., Liu, B. F., & Austin, L. L. (2011). Examining the Role of Social Media in Effective Crisis Management: The Effects of Crisis Origin, Information Form, and Source on Publics' Crisis Responses. Communication Research, 41(1), 74 –94.

Jong, W., Dückers, M. A., & Velden, P. G. (2016). Leadership of Mayors and Governors during Crises: A Systematic Review on Tasks and Effectiveness. Journal Of Contingencies & Crisis Management, 24(1), 46-58.

Kamphuis, W., Gaillard, A. W. K., & Vogelaar, A. L. W. (2011). The effects of physical threat on team processes during complex task performance. Small Group Research, 42(6), 700-729.

Kanawattanachai, P., & Yoo, Y. (2002). Dynamic nature of trust in virtual teams. Journal of Strategic Information Systems, 11(3-4), 187-213.

King, G. (2002). Crisis Management & Team Effectiveness: A Closer Examination. Journal of Business Ethics, 41(3), 235–249.

Kroenke, D. (2011). Using MIS (3rd ed.). Upper Saddle River,NJ: Pearson Prentice Hall.

Lester, P. B., & Gretchen, R. V. (2012). Swift Trust in Ad Hoc Military Organizations: Theoretical and Applied Perspectives. The Oxford Handbook of Military Psychology, Oxford University Press, 176-186.

Maitlis, S. (2005). The social processes of organizational sensemaking. Academy of Management Journal, 48, 21–49.

Mckinley, W., & Scherer, A. G. (2000). Some Unanticipated Consequences of Organizational Restructuring. Social Science Electronic Publishing, 25(4), 735-752.

Meyerson, D., Weick, K. E., & Kramer, R. M. (1996). Swift trust and temporary groups. Raj.rajaditi.com, 166-195.

Nemiro, J., Beyerlein, M. M., Bradley, L., & Beyerlein, S. (2008). The handbook of high performance virtual teams: a toolkit for collaborating across boundaries.

Nemiroff, P. M., & Passmore, W. A. (1975). Lost at Sea: A Consensus Seeking Task. La Jolla, CA: N.

Nienhaus, A. (2014). Exogenous Shock or Scapegoat: Making Sense of a Banking Crisis' Impact on Manufacturing Industries. Academy Of Management Annual Meeting Proceedings(1), 1.

Olson, B. J., Parayitam, S., & Bao, Y. (2007). Strategic decision making: The effects of cognitive diversity, conflict, and trust on decision outcomes. Journal of Management, 33(2), 196-222.

Paraskevas, A. (2006). Crisis management or crisis response system? a complexity science approach to organizational crises. Management Decision, 44(7), 892-907.

Radcliffe, L. L., & Schniederjans, M. J. (2003). Trust evaluation: an AHP and multi-objective programming approach. Management Decision, 41(6), 587-595.

Rafaeli, A., Ravid, S., & Cheshin, A. (2009). Sensemaking in virtual teams: the impact of emotions and support tools on team mental models and team performance. International Review of Industrial and Organizational Psychology, 151-182.

Reissner, S. C. (2011). Patterns of stories of organizational change. Journal of Organizational Change Management, 24(5), 593-609.

Sackman, S. (1991). Cultural knowledge in organizations: Exploring the collective mind[M]. Newbury Park, CA: Sage.

Salicru, S. (2017). Understanding the leadership crisis. Governance Directions, 69(8), 490-492.

Sauer, J., Felsing, T., Franke, H., & Rüttinger, B. (2007). Cognitive diversity and team performance in a complex multiple task environment. Ergonomics, 49(10), 934-954.

Stachowski, A. A., Kaplan, S. A., & Waller, M. J. (2009). The benefits of flexible team interaction during crises. Journal of Applied Psychology, 94(6), 1536-1543.

Stieglitz, S., Mirbabaie, M., & Milde, M. (2018). Social positions and collective sense-making in crisis communication. International Journal of Human-Computer Interaction, 1-28.

Suzanne, C., & Weisband, I. S. (1997). Developing Trust in Virtual Teams. Harvard Business Review, 2(6), 412 - 420.

Thomas, J. B., Clark, S. M., & Gioia, D. A. (1993). Strategic sensemaking and organizational performance: Linkages among scanning, interpretation, action, and outcomes. Academy of Management Journal, 36(2), 239-270.

Wall, E. (2014). Sense-making of risk and role-taking emotions: how young Swedes construe road traffic risk. Journal Of Risk Research, 17(10), 1285-1299.

Waller, M. J., Lei, Z., & Pratten, R. (2014). Focusing on teams in crisis management education: an integration and simulation-based approach. Academy of Management Learning & Education, 13(2), 208-221.

Webber, S.S. (2008). Development of Cognitive and Affective Trust in Teams - A Longitudinal Study. Small Group Research, 39(6), 746-769.

Wehrung, J. P. (2017). Displaying Narcissism in a Virtual Team. Management Revue, 28(4), 441-460.

Weick, K. E. (1988). Enacting sensemaking in crisis situations. Journal of Management Studies, 25, 305-317.

Weick, K. E., & Roberts, K. H. (1993). Collective Mind in Organizations: Heedful Interrelating on Flight Decks. Administrative Science Quarterly, 38(3), 357-381.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2005). Organizing and the process of sensemaking. Organization Science, 16(4), 409-421.

White, C., Plotnick, L., Addams-Moring, R., Turoff, M., & Hiltz, S. R. (2008). Leveraging A Wiki to Enhance Virtual Collaboration in The Emergency Domain. in Proceedings of the 41st Annual Hawaii International Conference on System Sciences (HICSS 2008), 1–10.

Xu, G., Feng, Z., Wu, H., & Zhao, D. (2007). Swift trust in a virtual temporary system: A model based on the Dempster-Shafer theory of belief functions. International Journal of Electronic Commerce, 12(93-126).

Yin, S., & Jing, R. (2014). A Schematic View of Crisis Threat Assessment. Journal Of Contingencies & Crisis Management, 22(2), 97-107.

Dark Web, Black Markets: Crisis as Opportunity

Kathleen Moore
School of Integrated Sciences
James Madison University
Moore8ka@jmu.edu

ABSTRACT

Black markets that develop after disaster events have potential to disrupt recovery efforts, and the Dark Web is the perfect facilitator of these markets. Lack of knowledge about the Dark Web: how to access it, how to safely, efficiently navigate the space, and prevailing myths about its dangers likely lead to this deficiency of research. To date, this area is a critically unexplored area of the Internet in the crisis research literature. This work examines this area of the Internet for utility and insight relevant to crisis managers. A pilot study on Puerto Rico in the months following Hurricane Maria reveals possible indicators of the development of black markets for prescription drugs, food, and water, which can impact long-term recovery and reconstruction efforts when these items are diverted from legal supply chains. As more people adopt this hidden part of the Internet, researchers and managers must do more to pay attention to activities that occur in this space.

Keywords

Deep Web, Dark Web, Surface Web, Black Markets, Crisis Response, Crisis Management

INTRODUCTION

Markets can suffer disruption and even failure during natural disasters or crisis events, which in turn can affect the recovery of an area (cite). Visible indicators of market disruption in the form of open-market price gouging are easily recognizable dealt with (Skarbek, 2008), however, invisible indicators in the form of supply chain diversions resulting in black markets are less recognizable. Supply diversions into black markets can impact the availability of goods, and with legal authorities often tasked with recovery activities during these chaotic times, illegal markets easily go undisturbed during these events (Dunlap et al, 2012). Illegal activities such as human trafficking is well-known to flourish immediately after crisis events (Stout, 2018), even paper currencies of countries in crisis are subject to this phenomenon (Flannery, 2018).

Since invention of digital (crypto) currencies in 2009, Dark Web illegal markets (DWIMs) have flourished, and to date, there are 54 active markets on the Tor Network. In theory, DWIMs are the perfect facilitator for black markets, however, have not been studied in the canon of crisis research. This is likely due to the complexity of the technology of the Dark Web, lack of understanding about this space, and the relative newness of its activities in the public consciousness, and also, until just recently, the capture of illegal market data was exceedingly difficult outside of government sponsored research national security agencies. However, prior to the emergence of DWIMs, goods were primarily sold in Dark Web forums and message boards, and in some cases, still are, thus allowing researchers an opportunity to examine this space for linkages and indicators of black-market activity.

After Hurricane Maria struck Puerto Rico in September 2017, and in the months following, certain activity in Dark Web forums suggest the development of a black market for supplies and prescription medicines that correspond with specific news announcements from the US Federal Emergency Management Agency (FEMA) in the year following. While this activity shows the potential for a black market, it may also signal the further need for a specific type of aid on the island. Lessons learned from this pilot study not only highlight the problems of studying this area of Internet, but also help establish guidelines for structuring future research in this space.

BACKGROUND

Black Markets and Disasters

Dark Web markets and forums are digital black markets, which are offline systems (markets) that operate outside the normal means of production and acquisition of goods and services (Folger, 2010). These markets often serve to subvert government control of prices and quantities or payments of taxes and have an impact on the forces of supply and demand of regular marketplaces (Michaely, 1954).

Black markets thrive best during and after crisis events when normal operations of a country are in disarray (Reynolds, 1998). Human Trafficking is an issue long known to increase during natural disasters when legal authorities are more engaged in rescue and relief efforts rather than dealing with crime (UNDOC, 2009). Drug related activity and diversion from normal supply chains have also long been an issue that thrives in this space and time (Forgione et al, 2001). More recently, countries whose currency falls in value during time of crisis experience the emergence of higher-value foreign paper currencies in black market (Flannery, 2018).

The Internet has long been a facilitator of black market activity where crime, fraud, and goods sold are facilitated by the coordinating benefits of the digital technology and the anonymity it used to offer (Baker 2002). As law enforcement became more apt at combatting certain types of cyber-crime, the need for increased anonymity and payments systems by criminals was satisfied by the Tor Network and new digital currencies that by-passed traditional banking systems and digital forensics (Gregg, 2012).

DARK WEB AND THE ONION ROUTER NETWORK

The Internet is a vast ecosystem with definable areas of content, and terminology not readily understood by many. The Internet itself is merely communications infrastructure consisting of hardware and software that allows enabled devices to connect. The World Wide Web (WWW) is an overlay or an application of the Internet that serves as an information space for resources and online documents that are searchable through Uniform Resource Locators (URLs) and are connected via hyperlinks. This structure makes the WWW highly interconnected, and thus, information discovery relatively simple. The Internet and WWW occupy the space referred to as Clear Net and Surface Web respectively.

There is also an "underbelly" to the system which includes areas of storage and hidden services, namely Deep and Dark Web. Deep Web is where Surface Web stores information not indexed by common web search engines such as Google, Explorer, or Safari. Content may include large databases, paid content, dashboards of websites or social media services, web mail, banking, etc. WWW users access this information daily and is a common online activity. Businesses, organizations, and government entities may employ the use of "Dark Sites" which are identical or "mirror" versions of their web sites that offer continuity of operations should their website go offline due to an emergency such as a technical problem or an emergency/crisis event. The sites are also known as hot and cold sites, where a hot site maintained by a company, in parallel to their functioning website, whereas a cold site is a site with the basic infrastructure, not updated in parallel but after crisis has struck, and is often maintained by a third-party vendor (SearchCIO, 2019).

Dark Web refers to hidden services available on the Internet but only accessible via a technological overlay to the Internet called Dark Net. Dark Net requires a specific tool called The Onion Router (Tor) to connect. The concept was invented by the United States Naval Research Laboratory in the mid-1990s and the technology was refined by the Defense Advanced Research Project Agency. Its purpose is to protect and secure intelligence-based communications online. Tor was launched in 2002, is free and available to the public, and is now managed by The Tor Project, Inc., a nonprofit organization devoted to the management of the network, research, and education (Tor Project, 2019).

When Tor is engaged, a user is able to access a volunteer network of nodes where the user's identity and data requests are anonymized, encrypted, and routed through a series of different servers before reaching the user's requested destination site (Figure 1). Users may use the technology to access and browse Surface Web sites, but the technology also allows them to access *.onion* sites, or hidden services sites which are Dark Web locations not accessible otherwise. The masking of IP addresses means users of this network may go relatively undetected, though technology is ever fully secure. Without IP addresses, this also means that much of the content on this network lacks the ability to be geolocated.

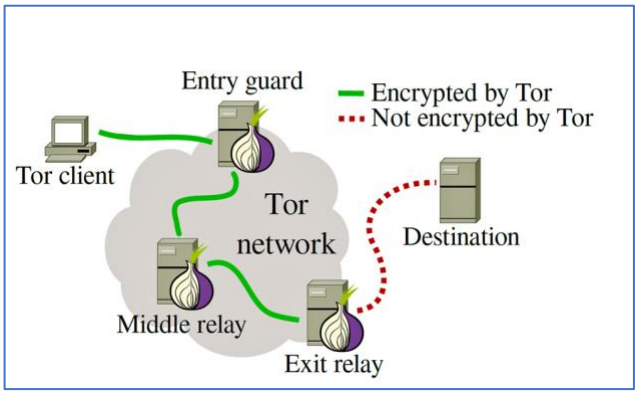


Figure 1: Tor relay network. Source: The Tor Project.

For nearly a decade, Tor not only secured intelligence communications, but was also utilized by activists, whistle blowers, and journalists around the globe in order to protect their identities online (Tor Project, 2019). This type of use continues alongside everyday citizens using the network who are concerned with protecting their data from overly intrusive collection practices by governments and corporations. Other Dark Web hidden areas exist such as i2P, Freenet, Gnu.Net, but due to lack of discernable activity, have been excluded from this study.

Dark Web's reputation took a turn in 2011 when Ross Ulbricht launched The Silk Road, an *.onion* site that allowed the anonymous purchase of illegal and prescription drugs, and other items using anonymous cryptocurrencies (Weiser, 2015). Tor also came to greater public attention when Edward Snowden, a former United States national security employee, exposed questionable, online, data collection practices by the US government. Since 2013, Dark Web has proliferated its number of drug markets, and other criminal services such as human trafficking, and child pornography (Power, 2014).

However, Dark Web is not the exclusive domain of illegal crime. Many myths and misconceptions abound concerning the use of Tor and Dark Web, and what type of content it contains. Many people believe that using Tor and/or visiting Dark Web sites constitutes illegal activity. In more repressive countries with strict laws on Internet use, this may be true, (Paul, 2015) but for most countries, this activity is legal provided the individual user does not engage in illegal activity in this space. While there is certainly disturbing information on Dark Web, many researchers speculate that much of it is benign (Winter, 2015) (Bartlett, 2015).

Dark Web also does not function like Surface Web. The Surface Web is highly interconnected and information easily discovered or suggested, whereas the shape of Dark Web is more clustered or siloed, with some sites existing as "islands" or "orphans" where one needs to know it exists and navigate directly to the site because it cannot be discovered by search engines (Hyperion Gray, 2018). Lastly, there is no "Google" for Dark Web. Instead, there is perhaps a dozen of privately maintained search engines that require manual updates of available *.onion* sites since they lack the ability of automated indexing due to the technology of the Dark Web. These engines have arying levels of indexing, so persons need to visit a variety of them and enter search terms in order to find information. Overall, this makes exploring the Dark Web cumbersome for most people.

Dark Web is also subject to fraud, malware, and hacking, similar to Surface Web, but the infrastructure of Dark Net poses unique concerns where users are encouraged to layer technology to protect their personal machines (Beltov, 2016). Everyday users may employ firewalls and virtual private networks, while researchers often add virtual machines and virtual operating systems so as not to be attacked or banned when scraping data from sites.

DWIMs are sites similar to Surface Web marketplace sites like Amazon or Alibaba except in that they facilitate the sale of illegal goods. Until very recently – the time of this paper's writing – capturing data from these illegal markets was prohibitive for technological reasons. While one can visibly see what is being sold on DWIMs, one cannot see if a sale is conducted and where items are shipped. As such, when analyzing this sale activity, it was easier for researchers to study sales through forums, a precursor to DWIM sites, to analyze phenomenon. Forums posts not only notify readers of an item for purchase, but often provide threads speaking to the trustworthiness of the seller and answering question such as payments accepted and shipping locations.

Between myths and misconceptions, the difficulty in exploring Dark Web, and potential issues in collecting data, alongside the more pressing concerns of understanding illegal markets and human abuse, it is not surprising that this space has not been more thoroughly researched in crisis management and response. However, with specific information targeting and software, there is evidence of the Dark Web being utilized following a disaster event. With this in mind, this research seeks to answer the following questions:

RQ1: Given Tor's reliance on anonymity and lack geolocated data, is there other observable data that may indicate development of black markets in a disaster ridden area?

RQ2: How should the data garnered through the study of Dark Web be regarded?

DATA COLLECTION AND METHODS

Data for this study was collected from publicly available sources. Metrics regarding the use of Tor in countries around the world are available via the Tor Project website. Since Tor is a necessary component for accessing these forums and markets, understanding its use before and after the hurricane was essential.

Four forums on Dark Web were randomly selected for analysis. Though drug markets are numerous, and the availability of prescription drugs are apparent, transactions occur privately thus researchers are not able to determine shipping locations (in this case, whether drugs of concern are shipped to Puerto Rico). Additionally, most drug markets have mirror sites, similar to legal businesses for continuity purposes. Mirrors are useful when the original site generates too much traffic for a single server to support, or in the environment of Dark Web, when a single site has been seized and closed by legal authorities, operations is able to continue on other versions of the site. Aside from being unable to determine shipping location, and since these web addresses shift constantly, they are effectively a moving target that are difficult to capture and were excluded from this research.

The focus of data collection then became forums. For the sake of this work, "forums" is used as an umbrella terms for forums, message boards, chans, and chat rooms. The forums chosen for analysis were *onionland, eightchan, hiddenanswers, and intelcutout*. The sites were chosen due to their wide popularity and the variety of topics discussed. There are no formal metrics available for sites on the Dark Web, thus forum choice was determined by recommendations from the Hidden Wiki, a site that provide semi-regular updated lists of available forums. The four forums chosen have long been associated with this site.

Search terms included: Puerto Rico, emergency supplies (which varied as a catch-all for food, water, tools, medicine, and other miscellaneous items), water, food, medicine, and commonly needed prescription medicines such as insulin and antibiotics. Antibiotics were searched for by both generic and brand name and chosen due to the long list of available drugs, and also due to reports of bacterial disease outbreaks following the hurricane. All search terms were employed in both English and Spanish (though Spanish terms yielded no results). Since a structured collection platform was used to analyze captured data, Boolean String searches were performed using all the search terms to capture posts meeting the search criteria. The terms for medicine were chosen based on their common association to black markets. The terms food, water, and emergency supplies were chosen based on news reports of common needs during the period of data collection which was after the impact of Hurricane Maria on 20 September 2017, through 31 August, 2018.

ANALYSIS

Prior to Hurricane Maria striking the island of Puerto Rico, Tor use on the island averaged a modest 1,000 users on a daily basis (Tor Project, 2019). The population of the island is an estimated 3.1 million (Census.gov, 2019), so while this amount of use appears low (.00032 percent), Tor use on the United States mainland is only marginally higher (.0018 percent) (Tor Project, 2019). Since the island's infrastructure experienced large-scale damage, above electrical and telecommunication lines were inoperable on most of the island months after the event (Nestel, 2018). Naturally, connecting to Tor was impossible for many and use dropped to nearly 100 daily users at the end of 2017 before rebounding in 2018 up to 750 daily users through either direct or connection or through a proxy server (Figure 1).

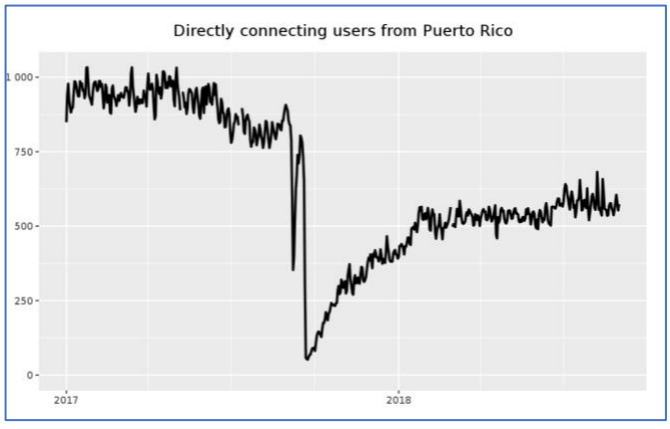


Figure 1: Direct Tor connection in Puerto Rico 2017 through August 2018.

Dark Web forums are not often explicit when it comes to understanding sale transactions. Participants in these forums can offer to sell, state an intention to buy, or pose a question about a particular good which is code that the post author intends to sell or buy then encouraging a backchannel communication. Of the four forums examined, the onionland forum yielded the largest number of search results in (Figure 2). For visualization purposes, the charts were condensed by moving average, meaning onionland yielded over 500 search results.

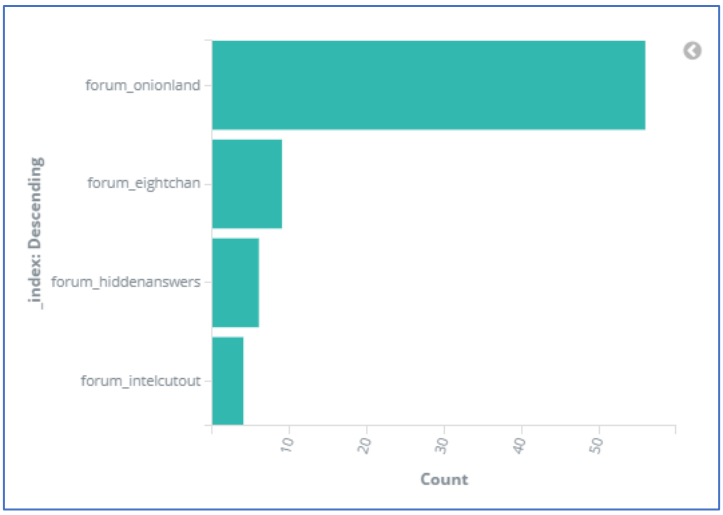


Figure 2: Search results by average of 10, by forum.

Comprehensively looking at all forums, and filtering for references specific to shipping to Puerto Rico, basic amenities such as food, water, and medicine were consistent throughout the period of analysis, but exhibited specific spikes in June 2018. Requests to buy food, water, medicine, and general supplies in bulk were the most requested at 500, 300, and 250 individual requests respectively during this time frame (Figure 3).

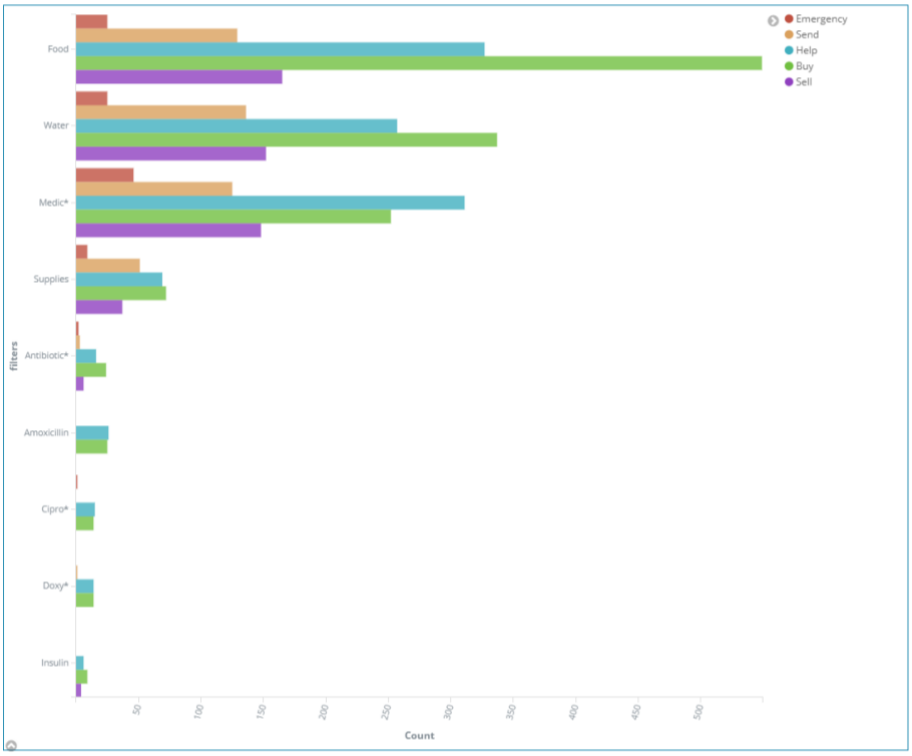


Figure 3: Items for sale or requested in Puerto Rico, June 2018.

When prescription drugs were analyzed across forums during the period of analysis, the occurrence counts shift from those looking to buy to those looking to sell. This phenomenon happens several times during the months following the hurricane but shifts to more posts explicitly offering to sell antibiotics during June 2018. An analysis of news events concerning Puerto Rico during this time reveal most of these spikes corresponding with news reports on 1 June concerning FEMA scaling back operations on the island, and reports on 29 and 30 June concerning citizens losing FEMA provided housing and stores of bottled water being stranded in airports (FEMA, 2018) (Figure 4). Charts were condensed by moving averages of 10, meaning the large spikes in June report nearly 300 requests.

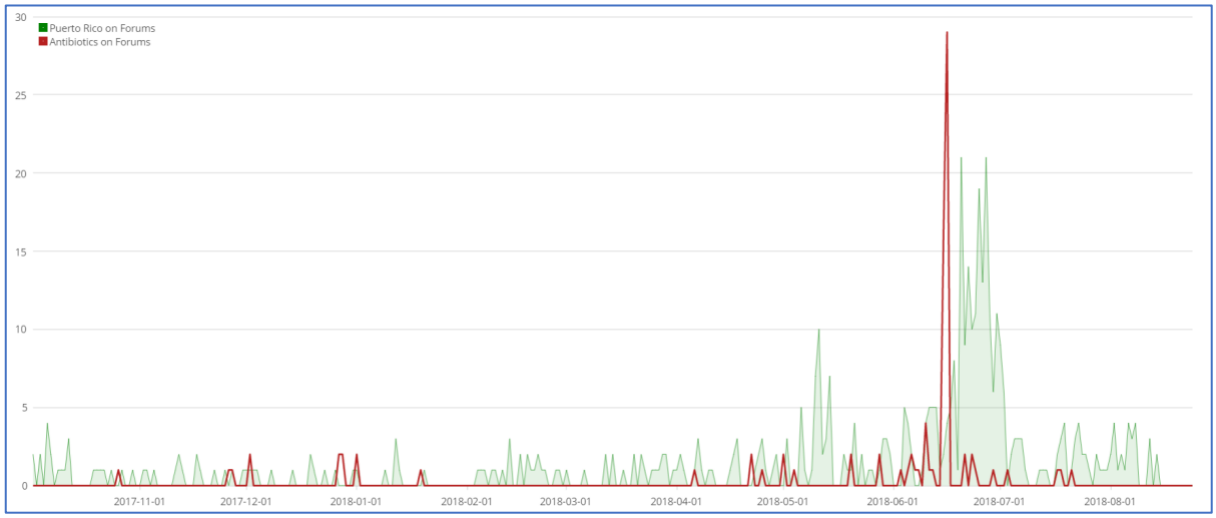


Figure 4: Antibiotic buy/sell spikes, by average of 10, on Dark Web forums in June 2018.

DISCUSSION

Because Dark Web does not possess multiple comprehensive search engines, and because items can be sold in a variety of places, compounded by the fact that drug market sites do not publicly discuss sales locations, it can be difficult to identify information in this environment that signifies a problem in long-term disaster recovery. To capture sales information, particularly geolocated data, different technology capture mechanisms must be employed when scraping drugs market sites. At the time of this writing, there were 59 recognizable drug markets either on or offline (Dark Web News, 2019). Since drug markets are effectively a moving target where their site addresses change as they add mirror sites to escape detection, unless using a specialized software to capture data, researchers must be diligent in discovering new *.onion* addresses where the market may also be operating. However, despite these difficulties the more resilient DWIMs offer technological security and take the burden of payment processing off the vendor, making them the obvious choice for those looking to sell goods in this space. It is likely that less experienced black marketeers may be going to forums due to ease of use.

Within forums, the dynamic is different. Posts stating offers to buy or sell that result in a potential sale also hold further communication in a backchannel, such as a direct messaging functions, and that information is also not available to data scrapers. The utility of analyzing forums lies in the fact that posts can become location specific. Sellers offer to ship to a location and buyers will ask if a product can be ship to a specified location. Public replies to either type of posts also help geolocate a potential sale. In this case, while there was consistent low-level activity of this nature in the time frame following the hurricane, there was an unusual and marked increase in June 2018. In examining both English and Spanish posts concerning these items and recovery efforts, and the specific timing of news versus spikes of activity, it is reasonable to assume that the FEMA news reports precipitated these increases. In the end, the question becomes: if this activity is present within forums, how much more activity can we assume is occurring in the DWIMs, which are now the preferred method for selling and buying. With the technology more recently available to researchers, analyzing DWIMs may now be an option.

In light of this, crisis managers must decide whether the mere presence of an offering or a request for an item, and in what discoverable numbers, may indicate a specific need in an area of recovery. Though the numbers reported in this research appear low, it is important to compare the number of requests to the number of online Tor users. In this case, there was an average of 700+ daily Tor users in Puerto Rico during the data capture period but nearly three-times the number of unique requests for emergency supplies and medicine in June alone. Proportionally,

this number is significant. And while these items may be used to fuel black markets, authorities should keep in mind that these types of markets also operate under general principals of supply and demand, meaning acquiring these items for re-sale is very likely reflective of demand on the ground (Nayeri and Lopez-Pardo, 2005). On an island like Puerto Rico which is governed by the Joes Act restricting who may deliver goods, any diversions from legal supply chains to black markets can have an immediate and noticeable effect.

What is most concerning in this analysis is not the sell/request for prescription drugs diverted from legal channels and funneled to black markets, but the higher number of requests for food and water. Federal authorities can more easily assist with drug diversion activities, but are less likely to help with food and water theft adding to already overwhelmed local police agencies. This information may indicate to crisis managers either an existing or an anticipated need.

How do managers effectively use this information highlights an issue of trust. How trust is extended when the environment is purposefully anonymized and is known to facilitate illegal activity is serious question. Accepting information in this area of the Internet may be akin to the problems social media faced in its early days. New technology and lack of its adoption often breeds mistrust (Tapia et al, 2011) (Tapia et al, 2013). Crisis managers may consider this type of information as ambient, meaning they could use this information contextually to supplement on-the-ground knowledge of existing conditions. Comparing Dark Web posts to Surface Web social media may help further illuminate whether there is true on the ground need or help legitimize data from Dark Web as many assumptions must be made about information derived in this environment.

Lastly, where Tor Network is available, novice black marketeers will not remain so permanently. As novice vendors become more comfortable with the technology and the environment, they are less likely to remain with forums and move to DWIMs over time, thus highlighting the need for more crisis research on the Dark Web.

CONCLUSION AND LIMITATIONS

Data for this pilot study was scraped from a small number of sources well after the occurrence of events, so there was no opportunity to re-target search terms or scrape additional sources. Data collection sites included only four forums. Given the number of available markets where location is difficult to ascertain, and the unknown number of forums, future researchers should monitor as many as they can identify. With high proportional results presented in this pilot study, expanding the number of collection sites will very likely yield significantly more evidence. Given the unknown size of the Dark Web and its lack of interconnectedness, it is difficult to know how many sites exist. Some numbers range from as little as 7 thousand to as high as 40 thousand *.onion* sites (Hyperion Gray, 2018). For context, the WWW, even with interconnectedness and robust search engines, is equally unknowable due to its size and estimated to have as many as 1.5 billion (Internet Live Stats, 2019).

Further, despite the posting of sale items or requests to buy with Puerto Rico as the proposed shipping location, any completed sales transaction would occur privately in backchannel communication areas, so whether the sale was completed is unknown. Also, it is not uncommon for markets and forums targeted by government agencies for illegal activities to frequently go offline due to seizure or from being blocked. These sites may reappear after a while on a different *.onion* site, or may be permanently closed, thus data capture is time sensitive in this environment. Since data capture of these markets is now available outside of government circles, examining both forums and illegal markets sites during future events may help determine size and scope of emerging black markets in a given area after a crisis.

As more people adopt anonymous web browsing and as illegal markets continue to flourish, and as researchers develop more tools to safely and efficiently navigate this environment, the Dark Web yields tremendous potential in crisis research in the context of information systems. Researchers with knowledge of this environment knowing where and how to target data, opens potential new research opportunities in areas of: GIS, Social Media, Logistics and Supply Chain Management, Privacy, Healthcare, and Community Engagement.

ACKNOWLEDGEMENT

Data for this research was derived using a platform provided by a US-based company who monitors Dark Web activity for commercial and government clients, as such, this company wishes to remain anonymous.

REFERENCES

Baker, CR. (2002) Crime, fraud and deceit on the internet: is there hyperreality in cyberspace? *Critical Perspectives on Accounting, 13(1), pp. 1-15.*

Beltov, M. (2018) Do's and Don'ts of Dark Web. Sensortechforum.com. https://sensorstechforum.com/dos-

donts-dark-web/

Bartlett, J. (2015). How the mysterious dark net is going mainstream. Ted.com. https://www.ted.com/talks/jamie_bartlett_how_the_mysterious_dark_net_is_going_mainstream

Census.gov. (2019) Quick Facts: Puerto Rico. https://www.census.gov/quickfacts/fact/table/pr,sanjuanmunicipiopuertorico,sanjuanzonaurbanapuertorico/LND110210

Darkwebnews.com (2019) Dark Web Market List. https://darkwebnews.com/dark-web-market-list/

DisasterAssistance.gov (2019) Emergency Food and Water. https://www.disasterassistance.gov/information/immediate-needs/emergency-food-and-water

FEMA (2018) News Releases: Puerto Rico. FEMA.gov. https://www.fema.gov/states/puerto-rico

Finn, P., and Horowitz, S. (2013) U.S. charges Snowden with espionage. The Washington Post. https://www.washingtonpost.com/world/national-security/us-charges-snowden-with-espionage/2013/06/21/507497d8-dab1-11e2-a016-92547bf094cc_story.html?utm_term=.c88cac03c154

Flannery, NP. (2018) Venezuela's Economic Crisis Keeps Getting Worse. Forbes.com https://www.forbes.com/sites/nathanielparishflannery/2018/03/22/venezuelas-economic-crisis-worsens-in-2018/#6031c1cc1f17

Folger, J. (2010) The Big Business of Black Markets. Investopedia.com. https://www.investopedia.com/financial-edge/0310/march-4-the-business-of-black-markets.aspx

Forgione, DA., Neuenschwander, P., Vermeer, TE. (2001) Diversion of prescription drugs to the black market: what the states are doing to curb the tide. *Journal of Health Care Finance, 27(4), pp. 65-78.*

Greenberg, A. (2013) FBI Says It's Seized $28.5 Million in Bitcoin from Ross Ulbricht, Alleged Owner of Silk Road. Forbes.com. https://www.forbes.com/sites/andygreenberg/2013/10/25/fbi-says-its-seized-20-million-in-bitcoins-from-ross-ulbricht-alleged-owner-of-silk-road/#1dcf76c02765

Gregg, B. (2012) How Online Black Markets Work. CSO Online.com https://www.csoonline.com/article/2131589/how-online-black-markets-work.html

Hyperion Gray (2018) Dark Web Map. HyperionGray.com https://www.hyperiongray.com/dark-web-map/

Internet Live Stats.com (2019) http://www.internetlivestats.com/total-number-of-websites/

Michaely, M. (1954) A Geometrical Analysis of Black Market Behavior. *The American Economic Review, Vol. 4, No. 4, (Sept 1954) pp. 627-637.*

Nayeri, K, and Lopes-Cardo, C.M (2005) Economic Crisis and Access to Care: Cuba's Health Care Systems Since the Collapse of the Soviet Union. *The International Journal of Health Services, Vol 3, Issue 4, (Oct 2005) pp. 613-630.*

Nestel, M.L. (2018). Electricity restored to 75 percent of customers in Puerto Rico: Utility. Abcnews.com. https://abcnews.go.com/US/electricity-restored-75-percent-customers-puerto-rico-utility/story?id=53005459

Power, M. (2014) Life After Silk Road: How the Online Drug Market is Booming. The Guardian. https://www.theguardian.com/technology/2014/may/30/life-after-silk-road-how-the-darknet-drugs-market-is-booming

Paul, K. (2015) Russia Wants to Block Tor but it Probably Can't. MotherboardVice.com. https://motherboard.vice.com/en_us/article/ypwevy/russia-wants-to-block-tor-but-it-probably-cant

Reynolds, D.B. (1998) Soviet Economic Decline: Did an Oil Crisis Cause Transition in the Soviet Union? *The Journal of Energy Development, Vol. 24, No.1 (Autumn 1998), pp. 65-82.*

SearchCIO (2019) Definition: Hot site and cold Site. TechTarget.com https://searchcio.techtarget.com/definition/hot-site-and-cold-site

Skarbeck, D. (2008) Market failure and natural disasters: A Reexamination of anti-gouging laws. *Public Contract Law Journal 37(4) pp. 771-780.*

Stout, Samantha, "Human Trafficking in the Wake of Natural Disasters: is the United States Any Different Than Third World Countries?" (2018). Accounting Undergraduate Honors Theses. 27. http://scholarworks.uark.edu/acctuht/27Third World Countries?

Tapia, A., Bajpai, K., Jansen, B., Yen, J. (2011). Seeking the **trustworthy tweet**: Can microblogged data fit the information needs of disaster response and humanitarian relief organizations. Proceedings of the 8th

International ISCRAM Conference, Lisbon, Portugal, May, 2011.

Tapia, A. Moore, K., Johnson, N. (2013) Beyond the trustworthy tweet: A deeper understanding of microblogged data use by disaster response and humanitarian relief organizations. Proceedings of the 10th International ISCRAM Conference, Baden-Baden, Germany, May 2013.

The Tor Project. (2019) Metrics. https://metrics.torproject.org/userstats-relay-country.html

The Tor Project. (2019) Overview. https://www.torproject.org/about/overview.html.en

United Nations Office on Drugs and Crime (2009). *A Global Report on Trafficking in Persons*.

Weiser, B. (2015) Man Behind Silk Road Website Convicted on All Counts. The New York Times. https://www.nytimes.com/2015/02/05/nyregion/man-behind-silk-road-website-is-convicted-on-all-counts.html

Winter, A. (2015) The Dark Net isn't what you think. It's actually key to our privacy. Ted.com. https://www.youtube.com/watch?v=luvthTjC0OI

Integrating citizen initiatives in a technological platform for collaborative crisis management

Robin Batard
Télécom ParisTech
IMT Mines Albi
robin.batard@telecom-paristech.fr

Aurélie Montarnal
IMT Mines Albi
aurelie.montarnal@mines-albi.fr

Frédérick Bénaben
IMT Mines Albi
frederick.benaben@mines-albi.fr

Caroline Rizza
Télécom ParisTech
caroline.rizza@telecom-paristech.fr

Christophe Prieur
Télécom ParisTech
christophe.prieur@telecom-paristech.fr

Andrea Tapia
The Pennsylvania State University
atapia@ist.psu.edu

ABSTRACT

Although they can make a significant contribution to crisis response and management, citizens tend to be underestimated and under-integrated by official crisis responders. There is a necessity to take citizen contribution into crisis management tools, both for the information they can provide (*information-focused volunteers*) and the actions they can carry out (*action-focused volunteers*). Therefore, professionals need to be aware of the diverse ways citizens can help them to manage a critical situation: obviously by improving the situational awareness, but also by spontaneously performing tasks to meet specific needs on the ground.

After presenting the RIO-Suite software, a crisis management tool based on collaboration of stakeholders, this paper suggests ideas about how to make the most of action-focused volunteers to improve the orchestration of the crisis response. Given a volunteer action, four possible decision types are identified: Ignore, Stop, Consider and Support, and their consequences on 1) the crisis response and 2) the collaboration process are presented.

Keywords

Citizens, Volunteers, Integration, IT Solution

INTRODUCTION

Information and Communication Technologies (ICT) and social media drastically changed the way information is shared and structured in times of crisis (Alexander 2014). Thanks to these powerful tools that give them a voice, citizens are becoming more and more influent in crisis situations. Their participation is fostered, and the concept of volunteerism in crisis situations is broadened, to include emergent unaffiliated citizen initiatives (Stallings and Quarantelli 1985; Whittaker et al. 2015). More than simple information sources, they sometimes act directly on the ground, or use social media as their own crisis management tools (to organize the response, exchange information, communicate about their actions…). Sometimes formally organized as official helping groups, sometimes acting independently, spontaneously and with unpredictable skill levels, citizens play heterogeneous roles, and the volunteer behaviors are many and varied.

With such a diversity of new unconventional actors to take into account, some important challenges are rising up. Among them, the question about the collaboration between official crisis managers and citizens. Indeed, among the profusion of volunteer types in crisis situations, some emergent groups tend to be more difficult to understand and to manage than traditional crisis management stakeholders. Official crisis responders must be aware that unsolicited volunteers will always show up during crisis events (der Heide 2003). Thus, there is a definite need to

integrate social media data and volunteer initiatives in crisis management tools to improve the situational awareness and take more appropriate account of citizens' help (Vieweg et al. 2010; Yin et al. 2015).

Considering cooperation and communication of stakeholders as keys to crisis management efficiency, RIO-Suite is a suite of tools that aims to provide decision makers with a visual model of situation and a computable collaboration process model to orchestrate the crisis response. However, in its current stage of development, the only stakeholders taken into account by the software are official crisis responders. Thus, given the diversity of contributions that citizens can bring to the crisis response, the software development is now focused on broadening its scope to less formal stakeholders, aiming to be able to make the most of volunteer initiatives, and thus to support a collaborative answer to the crisis.

After studying the current status of citizens in crisis management, this paper will present the software RIO-Suite, which aims at integrating citizen initiatives into the situational awareness and the crisis response processes. Then, it will present the early stages of thinking regarding the integration of volunteer initiatives into the software. For the research presented in this paper, it is important to keep in mind that the goal is not to change the way citizens react to a crisis, but to help decision makers to understand volunteers' behavior on the ground, and be able to take decisions regarding how this behavior could improve the response.

LITERATURE REVIEW

Citizen consideration in crisis situations

About cooperation between professionals and citizens, Reuter et al.'s communication matrix for a social software infrastructure (2011) presents the current communication paths between official crisis response organizations and ordinary citizens (see Table 1). In some ways, professionals go no further than just picking information from social media (case (a)), and providing information or safety instructions to citizens (case (b)) through these tools.

Table 1. Reuter et al.'s (2011) communication matrix for a social software infrastructure

Sender \ Receiver	Organizations	Citizen
Organization	(d) Inter-organizational crisis management	(b) Citizen communication
Citizen	(a) Integration, aggregation and validation of citizen-generated content	(c) Self-help communities

As this matrix is focused on communication, it does not give a comprehensive point of view on the current cooperation considerations between professionals and citizens. In general, official crisis responders have preconceived ideas regarding citizen behavior. In a disaster, when by definition the resources and capacities of official crisis responders are insufficient to handle the needs, professionals tend to treat citizens as an unwanted nuisance (Glass 2001). They often establish a physical and psychological perimeter around the event, to keep the public out. This is what Glass (2001) calls the "yellow-tape" effect.

However, many research works regarding volunteers' role in times of crisis have shown that citizens can be much more than just senders and receivers of information (Glass 2001; Scanlon et al. 2014; Wenger et al. 1985). Although it is believed that the typical reaction of an ordinary citizen to a crisis situation is shock, panic, stress and disorganization, several social science studies have demonstrated that these responses do not represent the reaction of the majority of disaster victims (Perry and Lindell 2003). Several examples of crisis situations show how citizen groups can organize themselves in times of crisis, whether it is on the ground (Scanlon et al. 2014) or online (Eriksson and Olsson 2016). Thus, being aware of all these citizen initiatives to improve the situational awareness and the crisis response remains an important challenge that professionals have to cope with (Scanlon et al. 2014).

Citizen contribution in crisis response

The positive value of citizen organization and crowdsourcing

Several studies show how social media can be a powerful tool for communities to build disaster resilience (Dufty 2012; Rizza and Pereira 2014). Sometimes used as an alternative communication channel to improve the information responders have regarding the situation (Vieweg et al. 2014), sometimes used as a backchannel when

traditional communication channels are out of service (Sutton et al. 2008), sometimes used by citizens to provide psychological first aid, or foster solidarity and ethics of care (Rizza and Pereira 2014; Taylor et al. 2012)... Citizens appropriate social media in many ways to meet their needs. A variety of examples in the literature and related to several crisis contexts describe the many ways ICT in general have been used, and sometimes taken into account by professionals. To name a few, we can talk about the Facebook groups created and used by citizens to share and structure information regarding victims after the 2011 Genoa floods (Rizza and Pereira 2014), or the significant impact of crowdsourcing (Horita et al. 2013; Meier 2013) such as the 2.3 million people using the Tomnod[1] website to find the Malaysian Airlines flight MH370 (Fishwick 2014).

Even outside of social media, several examples show the organization that citizens can demonstrate on the ground, when they are faced to a crisis situation. Indeed, unlike what is shown in "disaster" movies, novels and press coverage, most citizens respond constructively and rationally to the crisis by addressing their needs with the most effective mobilization of the resources in their possession (Perry and Lindell 2003). Several examples of such behavior are given by Scanlon et al. (2014), highlighting how ordinary people can play a relevant and important role in disaster response.

Still some challenges to cope with

Although the contribution of citizens in crisis situations is convincing, challenges remain, particularly through the integration of social media into crisis management processes. According to extensive research on the subject, social media integration rises challenges both on technical and social aspects (Crawford and Finn 2015).

On the one hand, we can cite the data volume, quality, trust and format challenges, that need powerful algorithms to extract relevant data from a diversity of sources (Alexander 2014). To quote Goolsby (2009), one might say that finding useful information during a major event is "a little like panning for gold in a raging river".

On the other hand, beyond digital divide and access to information issues (Easton 2014), social media use to manage a crisis can lead to rumor propagation, panic or rise several ethical challenges, such as privacy or governance concerns (Rizza et al. 2014; Watson and Finn 2013).

Attempts to integrate citizens

From information gathering to crowd tasking: a variety of tools to benefit from citizen contribution

Several research projects have already taken the first steps towards the integration of citizens into the crisis response. Regarding social media data, a multitude of research projects are focused on gathering, filtering, analyzing, and interpreting data from social media to improve the situational awareness. Among them, we can present Aupetit and Imran's tool (2017) to help official crisis responders to monitor social media data and find critical information regarding the situation. Working closely with an American 9-1-1 call center, Grace et al. (2019) compare several social media data filtering methods to improve the situational awareness in local areas for emergency managers.

Outside of social media, several tools also tend to help crisis management organizations to get closer to the citizens and take advantage of their potential help. For example, the ISAR+ European research project[2] aims to make the most of ICT by developing a platform to empower citizens and Public Protection and Disaster Relief (PPDR) organizations in online and mobile communications (Flizikowski et al. 2014). For example, Auferbauer et al. (2015) present RE-ACTA, a tool under development which aims to selectively distribute tasks to a crowd of volunteers, resulting in a specified form of crowdsourcing: *crowd tasking*. However, although crowd tasking could be relevant for a certain type of volunteers wanting to play their part in the crisis management, some spontaneous unaffiliated forms of volunteerism will always remain independent, and for such types, attempts to command and control their tasks may be misguided and counterproductive (Whittaker et al. 2015).

Among the already deployed IT solutions to make the most of citizen contribution in times of crisis, several applications tend to register volunteers to be able to task them when needed. For example, *PulsePoint*[3] or *Staying Alive*[4] are two mobile applications aiming to alert the closest CPR-trained citizens and localize the closest Automated External Defibrillator (AED) in case of cardiac arrest emergencies. In a broader scope, the Facebook Safety Check aims to help people to declare themselves safe, provide local assistance or connect to providers in

[1] https://www.tomnod.com/
[2] https://www.zanasi-alessandro.eu/projects/isar/
[3] https://www.pulsepoint.org/
[4] https://www.stayingalive.org/

case of emergency or disaster. In a more indirect way, crowdsourcing-based tools such as Waze[5] can also help professionals to get information or modify the road traffic in a crisis situation, and thus benefit from the crowd contribution to improve the crowd geographic distribution.

The potential of Intermediary Organizations

Following the idea that collaboration from the officials' perspective is hampered by a lack of an intermediary person to create a link between emergent groups and public authorities (Stallings and Quarantelli 1985), Zettl et al. (2017) defend the need of *intermediary organizations* to bridge the coordination gap. After presenting a long list of research projects which aim to fill this gap, they present two tools to support this concept of intermediary organizations: City-share, a situated public display application, and Security Arena, an inter-organizational platform. The purpose of these two crowd-based tools is to foster collaborative resilience between professionals, organizations and emergent volunteers.

The objectives of such tools are in line with the current status of the Volontaires Internationaux en Soutien Opérationnel Virtuel (VISOV) association, the French-speaking equivalent of the Virtual Operational Support Teams (VOST). Indeed, the VISOV association has signed agreements with official crisis management institutions in France, and its volunteers act as an intermediary link between citizens sharing information through social media, and official crisis responders. When a crisis occurs, the VISOV are 'activated', and they use collaborative tools to filter and share useful social media information to professionals.

Moreover, even in less formal contexts, many crises have seen the emergence of organized groups of citizens who remain in place after the events, building organizational networks and strengthening community resilience. For example, we can think about the Facebook group "Angeli col fango sulle magliette" in Genoa (Rizza and Pereira 2014), or the networks *Second Planet* in Frankfurt and *Train of Hope* in Vienna (Zettl et al. 2017), all of them created to address specific needs during a crisis, and remaining several years after to keep sharing crisis-related information.

Professionals and citizens: a need to cooperate

Organizations in charge of emergency management need to realize that involving citizens does not interfere in their protocols by making them less efficient (Díaz et al. 2013). Actually, according to Benaben et al. (2016), collaboration and coordination of stakeholders are key requirements of crisis management. Thus, by improving their cooperation, professionals and citizens could both be aware of others' needs, and thus contribute together in a more effective way to (i) improve the situational awareness and (ii) organize the crisis response.

However, to date, there is a lack of frameworks to create a comprehensive and manageable process to ensure the most effective and safe response with the aid of spontaneous volunteers (Orloff 2011). Thus, more adaptive and inclusive models of emergency and disaster management must be developed to integrate these volunteers into the response and harness the capacities and resilience that exist within and across communities (der Heide 2003; Whittaker et al. 2015).

RIO-Suite, a suite of crisis management tools based on collaboration between stakeholders

To provide professionals with the best possible understanding of the situation all along the crisis response, and to orchestrate the tasks carried out by stakeholders in real time, researchers at IMT Mines Albi's Industrial Engineering Centre developed the RIO-Suite platform. This platform is based on a *metamodel* (i.e. a set of generic concepts and their relations) for knowledge management in crisis management, presented by Benaben et al. (2016). Thanks to a diversity of data sources, such as sensors, official crisis management procedures, or social media, the RIO-Suite software aims to *instantiate* (i.e. identify) concepts of the metamodel in the crisis situation. In other words, the goal for the software is to provide the most comprehensive digital representation of the situation on the ground, to then be able to deduce the most appropriate collaborative behavior schema and then orchestrate it as the crisis response.

[5] https://www.waze.com

This metamodel (see Figure 1) consists of a *Core* part, representing the concepts presents in any collaborative situation, and four packages that are an extension of the core concepts, dedicated to crisis management situations:

- **The Partners** (left part): these concepts represent the stakeholders, their capacities and their resources, that might be needed during the crisis response.
    - E.g.: A firefighter (*actor*) has the ability to extinguish a fire (*service*) with a fire hose (*resource*).
- **The Context** (top part): these concepts are all the stakes and contextual elements that can take part in the crisis situation.
    - E.g.: A museum (*good*), the visitors inside it (*people*) or a regional nature reserve (*natural site*) might be affected (damaged or injured) by an intrinsic risk of flooding (*risk*) if they are present in an area liable to flooding (*danger*).
- **The Objectives** (right part): Whereas given a geographical area we might be able to know the *Partners* and *Context* concepts, the *Objectives* are concepts given by the crisis itself. These concepts represent all the elements that define the crisis and can have an effect on the events.
    - E.g.: A starting fire (*fact*) and a fragilized building (*emerging risk*) must be considered as objectives (*mission*). Besides, the wind or the rain will change the seriousness of the fire (*gravity factor*) while a bad social climate may change the nature of the crisis (*complexity factor*).
- **The Behavior** (bottom part): This package is slightly different from the three previous ones. It defines the rules to orchestrate the collaboration in the crisis management processes. This package is inspired by the Business Process Model and Notation (BPMN) standard for process modeling.
    - E.g.: The orchestration process (*collaborative process*) can be composed of a list of actions (*task*) carried out by organizations (*partner pool/lane*), arranged in a specific order (*sequence flow*), and assisted by the flow of information (*message flow*).

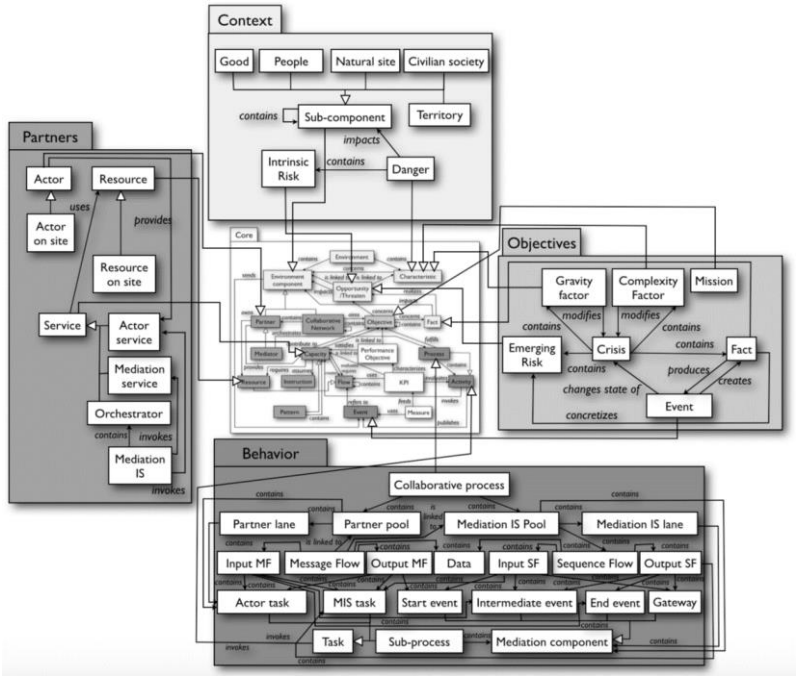


Figure 1. The RIO-Suite metamodel for knowledge management in crisis management (from Benaben et al. (2016))

Given all these inputs, the software is currently able to provide two outputs:

- A **Situational Model** with 1) a map of the stakeholders and the capabilities that they may need to mobilize, and 2) a cartographic vision of the issues at stake;
- A **Collaboration Process** to orchestrate the crisis, i.e. give advice to crisis managers regarding who should do what, at what time.

An overview of the input and output elements of the software are presented in Figure 2. To date, this model keeps being improved, so that it can be used for specific cases of crises, and to be sure it can embrace all types of collaborations in crisis management.

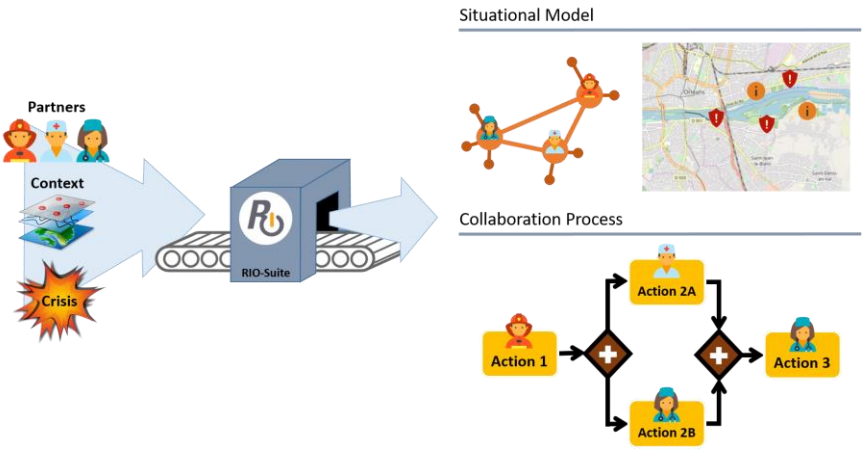


Figure 2. The current input data and output models of RIO-Suite

In the current state of development of the software, only official crisis responders, their skills and resources are taken into account as "Partners". To meet the definite need to integrate citizen initiatives into crisis management tools, the research is now focused on the volunteers, and seeks to make the most of their contribution.

PROPOSAL – INTEGRATING INITIATIVES TO SUPPORT CITIZEN-PROFESSIONAL COLLABORATION

Making the most of citizens' contribution: improve situational awareness and understand action

To capitalize on citizens' contribution in a crisis situation, the first need is to identify this contribution. In the literature, a large amount of research has been done to classify and categorize volunteers in crisis situations, but most of them were focused on the social structure of such initiatives. Distinguished between *Old* and *New structure* by Dynes (1970), *Individual* and *Organized* by Shaskolsky (1965), *Emergent* and *Organizational* by Wolensky (1979), *Formal* and *Informal* by Cnaan et al. (1996) and Whittaker et al. (2015), this social structure in which the volunteer initiative takes place tends to define its level of formalization, or its reliability from the officials' point of view.

Another strong distinction that appeared more recently between forms of volunteerism is related to the emergence of new initiatives fostered by the advent of ICT and social media in our society. Called *digital volunteers* by Whittaker et al. (2015), *virtual volunteers* by Reuter et al. (2013) as opposed to *real volunteers*, these emerging groups are identified by the communication channels they use rather than the initiatives they take.

However, among the diversity of citizen initiatives, from a group of people moving rubble in search of victims and an individual volunteer sharing a picture on Twitter, an important distinction that appears is that they don't provide all the same elements to the crisis response. While some volunteers perform or manage actions on the ground intending to help crisis responders or address personal needs, other ones share or organize information about the unfolding crisis, that might improve the situational awareness. In other words, when some volunteers are focused on the action, those focused on information help crisis responders to understand the first ones.

Thus, when looking at the RIO-Suite outputs, two ways of taking into account the citizen contribution appear:

- The *information-focused volunteers* will contribute to the situational model, by helping to instantiate new concepts of the metamodel. Thanks to the many information channels they use, from traditional ones to social media or other ICT, understanding the information shared by citizens can help to find new stakes, to identify a risk, or give insights on the progress of the crisis. This is in line with a profusion of work on the subject of social media data processing (Grace et al. 2019; Vieweg et al. 2010; Yin et al. 2015).
- The *action-focused volunteers* will contribute to the collaboration process, by carrying out actions thanks to their skills and their resources. Whether in a constructive or destructive way, these citizen initiatives will tend to change the situation on the ground, and might be detected by the *information-focused volunteers* or other stakeholders or tools (Ludwig et al. 2017; Neubauer et al. 2013).

By setting aside the method of identifying these *action-focused volunteers*, the next steps in this article will aim to discuss decision types regarding their potential integration into the crisis response process.

Towards integration of action-focused volunteers

From this objective, we can identify two main areas of research, that will be detailed below:

- What status should a volunteer initiative take?
- How to update the collaboration process with an identified initiative?

Status of the volunteer initiative: parameters influencing decision-making

Given a group of people moving rubble to find victims after an earthquake, what parameters can make the decision-makers change from wanting to stop them doing this action to wanting to provide them tools to improve their efficiency? Such a decision might rely on a list of implicit or explicit parameters. Here are some possible elements of influence on the decision:

- The **reliability** of the initiative can be a deterministic element for the decision making. This element includes the criteria of affiliation and skill level, which can be closely linked to each other in some cases. Indeed, it will be easier for professionals to cooperate with a volunteer registered with an official organization such as a volunteer firefighter whose skills are known, than cooperating with spontaneous unaffiliated volunteers with uncertain skills;
- The **ethical and social aspects** that integrating a volunteer initiative might represent, and the risk that this integration might represent for the volunteer him/herself;
- The **variety and volume of the needs to address**: depending on the size of the crisis and its intrinsic characteristics, professionals might estimate that they have enough resources to address all the needs or not;
- The **professionals' competences and resources**: whereas the former parameter defines the needs created by the events, the diversity and number of official responders and the scope of their skills will define their control of the situation;
- The **professionals' attraction and experience** with the use of social media and their openness to citizen contribution.

Such parameters might be deterministic for professionals to decide whether an initiative should be taken into account, ignored or stopped to improve the response. Moreover, all along the crisis response, the unfolding events might change the implicit value of these parameters, and consequently change the way professionals perceive a volunteer initiative.

Update the collaboration process from citizen action

Secondly, how can a citizen action influence the crisis management process? Indeed, as the software creates a process model describing collaborative behavior to respond to the crisis, if the goal is to have an agile management of this process, everything that happens during the crisis should be taken into account. In such a context, with the means and skills in their possession, citizen contribution for the response can be constructive, neutral or even destructive. For example, we can imagine that citizens can either start by themselves to fulfill a task that was assigned to other partners, or act in the opposite way and unintentionally create new tasks that will need to be accomplished by other partners. In both cases, crisis managers need to understand the way citizens behave, to be able to instantiate a new task or a new sub-process, or change the way tasks are assigned to stakeholders.

An overview of the prospective improvements that citizen integration can bring to RIO-Suite and its outputs is presented in Figure 3. Volunteers, whether they are known in advance or not, can be considered as additional partners. Thus, knowing their skills, resources and tasks in progress could improve the common operational picture (i.e. situational model) and update the collaboration process in several ways.

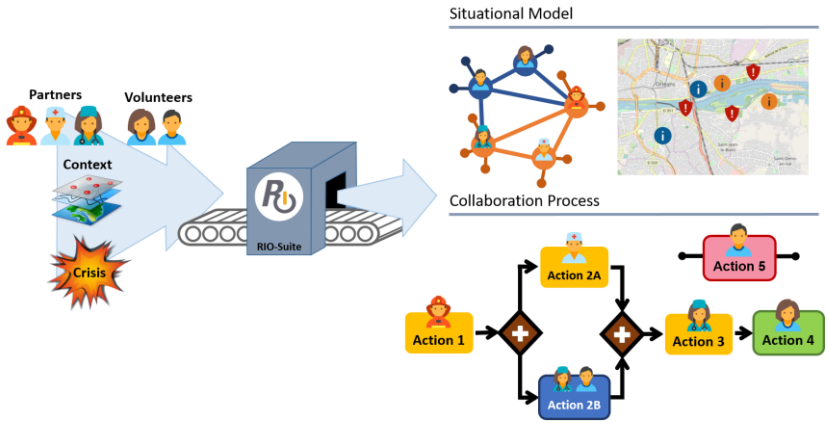


Figure 3. The target situation after taking into consideration the citizen initiatives into RIO-Suite

Different types of decision and their respective consequences

Given the different parameters that can influence the decision making regarding a citizen initiative, four types of decision have been identified, listed below with examples of crises during which such decisions were taken or should have been taken:

- Ignore
  - E.g.: During the 2015 migrant crisis in Europe, hundreds of refugees arrived daily by train at German and Austrian train stations. Spontaneous groups of volunteers mobilized to provide relief to refugees. Suffering from a lack of clear political directives, humanitarian organizations were bypassed by citizens, resulting in a chaotic situation and pointing out the lack of institutionalized cooperation (Zettl et al. 2017).
- Stop
  - E.g.: Following the 1999 Golcuk earthquake in Turkey, a traffic jam of 32 kilometers of spontaneous aid volunteers blocked professional aid workers and rescue vehicles to get to the disaster location (Helsloot and Ruitenberg 2004). Identifying and finding ways to stop this mass movement could have helped to save lifes.
- Consider
  - As it will be explained later, the fact of *considering* a citizen initiative will not have any consequence on the crisis response on the ground, but it will result in incorporating the initiative process into the global collaboration process. In other words, *ignoring* and *considering* a citizen action will both have no impact on the ground.
- Support
  - E.g.: Soon after the Swissair 111 crash into the Atlantic Ocean in 1998, fishermen near the crash location immediately headed out to sea to search for survivors. Upon arrival at the accident site, the Royal Canadian Navy ship asked them to line up and help them searching systemically the area (Scanlon et al. 2014).

These types of decision will have different consequences, both in the crisis response and on the collaboration process, as presented in Table 2.

Among these four decision types, the easiest one to put into practice will be to *ignore* the identified citizen behavior. Indeed, this means being conscious that this behavior is happening, but doing absolutely nothing regarding it, both on the ground and on the crisis management process. However, being the easiest decision to take does not mean this is the smartest one, because it may mean missing a relevant opportunity for the crisis response, as it has been the case during the migrant crisis in 2015 (Zettl et al. 2017). The fact of *considering* a citizen initiative aims at letting them act, without trying to change their action or supervise them.

Although the professionals' intention might be completely different, the difference between *stopping* and *supporting* a citizen initiative is slight. Indeed, these two decisions may result in new tasks for professionals (responders or mediators), resource mobilization, and may bring several updates to the collaboration process. Further research work needs to be done to understand citizens' motivations when acting during a crisis, to understand which impact *stopping* or *supporting* them could have on their behavior.

Table 2. The four decision types regarding citizen initiatives, and the changes it brings to the response and to the RIO-Suite collaboration process

Decision type	Potential change in the crisis response	Potential impact on the collaboration process
Ignore	None	None
Stop	• Mobilize official crisis responders, their resources and their skills • Volunteers switching to another task • Anxiety, distrust from the population • Increasing complexity of the crisis	• Adding professional tasks
Consider	None	• Adding the current volunteer tasks
Support	• Mobilize official crisis responders, their resources and their skills • Dedicate resources to the citizen action	• Adding the current volunteer tasks • Removing, Updating or Adding professional tasks

DISCUSSION AND CONCLUSION

Given the previous research on the subject, a fifth type of decision could be added: *crowd tasking*, as some tools presented in the literature review do. As this decision aims to pre-register volunteers and control citizens' behavior in the crisis response, it doesn't appear in the scope of objectives of RIO-Suite so far.

The four decision types presented in this article, and the parameters of influence on the decision-making might be closely correlated. For example, given a volunteer initiative, the gravity or complexity of the crisis might change the decision professionals will make.

Among the parameters of influence on volunteer integration, some tend to increase the relevance for professionals to do it: the reliability of the initiative, the needs generated by the crisis, and the ethical and social possibilities for integration. The remaining parameters, the professionals' competences and resources, and their attraction and experience with social media might be limiting to make an opportunity happen: the more professionals are overwhelmed, the less time they will be able to devote to the integration. These first hypotheses of correlation between the parameters and the decision types are presented in Figure 4 and will be discussed in future research work, based on case studies, interviews and observations.

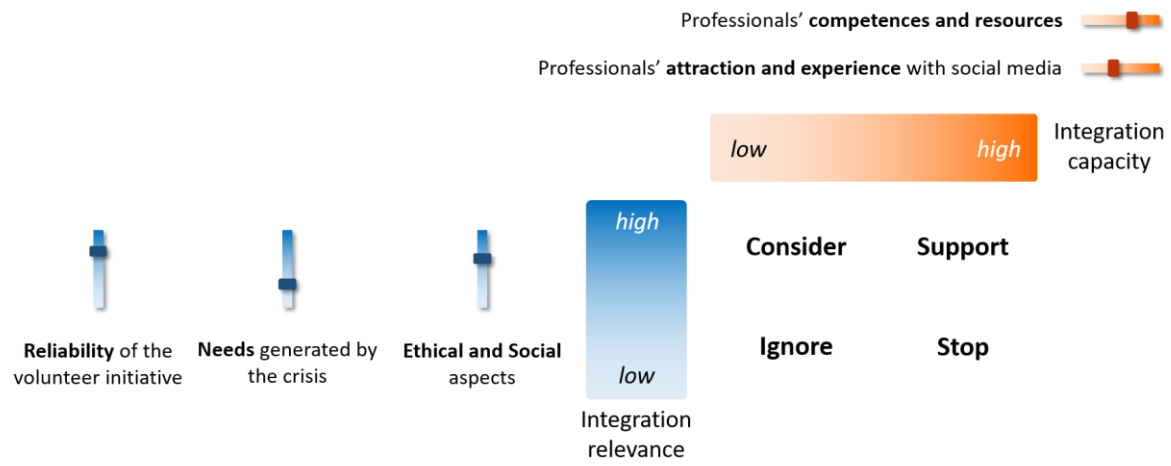


Figure 4. First attempt of framework for correlation between influence parameters and decision types

To summarize, this work in progress paper presents (i) the global parameters that can influence the crisis responders' decision making, and (ii) the four identified decision types regarding citizen initiatives. Future research work will focus on studying the correlations between (i) and (ii).

With the idea of integrating volunteers into RIO-Suite to foster multi-stakeholder collaboration, several works can be done for the future of this project:

- Test the robustness of the model by confronting it with specific case studies, interviews and observations;
- Find potential weaknesses of this model and suggest changes to make it more inclusive for all types of events;
- Propose possible additional layers to specialize it to the integration of citizens and their tools

Regarding the detection of the *action-focused volunteers*, social media are one of the few ways to detect such initiatives. Thus, when making decisions regarding volunteer integration for the crisis response, it should be kept in mind that the only volunteers that can be detected are those whose action can be shared through social media or other ICT. In addition, outside the crisis management unit, decisions taken by professionals on the ground must be taken into account in the crisis management process.

REFERENCES

Alexander, D. E. (2014). "Social Media in Disaster Risk Reduction and Crisis Management." *Science and Engineering Ethics*, 20(3), 717–733.

Auferbauer, D., Ganhör, R., and Tellioğlu, H. (2015). "Moving Towards Crowd Tasking for Disaster Mitigation." *Community Engagement*, 6.

Aupetit, M., and Imran, M. (2017). "Interactive Monitoring of Critical Situational Information on Social Media." *Proceedings of the 14th International Conference on Information Systems for Crisis Response And Management*, 673–683.

Benaben, F., Lauras, M., Truptil, S., and Salatge, N. (2016). "A Metamodel for Knowledge Management in Crisis Management." *HICSS 2016 - 49th Hawaii International Conference on System Sciences*, Proceedings of the Annual Hawaii International Conference on System Sciences, Bui, TX, Sprague, and RH, eds., IEEE COMPUTER SOC, Koloa, Hawaï, United States, 126–135.

Cnaan, R. A., Handy, F., and Wadsworth, M. (1996). "Defining Who Is a Volunteer: Conceptual and Empirical Considerations." *Nonprofit and Voluntary Sector Quarterly*, 25, 364.

Crawford, K., and Finn, M. (2015). "The limits of crisis data: analytical and ethical challenges of using social and mobile data to understand disasters." *GeoJournal*, 80(4), 491–502.

Díaz, P., Aedo, I., Romano, M., and Onorati, T. (2013). "Supporting citizens 2.0 in disasters response." *MeTTeG 13: 7th International Conference on Methodologies, Technologies and Tools enabling e-Government, October 17-18, 2013, University of Vigo, Spain, 2013, ISBN 978-84-8158-617-6, págs. 79-88*, Servizo de Publicacións, 79–88.

Dufty, N. (2012). "Using social media to build community disaster resilience." *Australian Journal of Emergency Management, The*, 27(1), 40.

Dynes, R. R. (1970). *Organized Behavior in Disaster*. Heath Lexington Books.

Easton, C. (2014). "The digital divide, inclusion and access for disabled people in IT Supported Emergency Response Systems: A UK and EU-based analysis." *Proceedings of the 11th International Conference on Information Systems for Crisis Response And Management*.

Eriksson, M., and Olsson, E.-K. (2016). "Facebook and Twitter in Crisis Communication: A Comparative Study of Crisis Communication Professionals and Citizens." *Journal of Contingencies and Crisis Management*, 24(4), 198–208.

Fishwick, C. (2014). "Tomnod – the online search party looking for Malaysian Airlines flight MH370." *The Guardian*.

Flizikowski, A., Kurki, T., Hołubowicz, W., Stachowicz, A., Päivinen, N., Hokkanen, L., and Delavallade, T. (2014). "Social Media in Crisis Management – the iSAR+ Project Survey." *Proceedings of the 11th International Conference on Information Systems for Crisis Response And Management*, 5.

Glass, T. A. (2001). "Understanding Public Response to Disasters." *Public Health Reports*, 116, 5.

Goolsby, R. (2009). "Lifting Elephants: Twitter and Blogging in Global Perspective." *Social Computing and Behavioral Modeling*, Springer US, 1–6.

Grace, R., Halse, S., Aurite, W., and Tapia, A. (2019). "Expanding Awareness: Comparing Location, Keyword, and Network Filtering Methods to Collect Hyperlocal Social Media Data." 10.

der Heide, E. A. (2003). "Convergence behavior in disasters." *Annals of Emergency Medicine*, 41(4), 463–466.

Helsloot, I., and Ruitenberg, A. (2004). "Citizen Response to Disasters: a Survey of Literature and Some Practical Implications." *Journal of Contingencies and Crisis Management*, 12(3), 98–111.

Horita, F. E., Degrossi, L., Assis, L. F. de, Zipf, A., and Albuquerque, J. P. de. (2013). "The use of Volunteered Geographic Information (VGI) and Crowdsourcing in Disaster Management: a Systematic Literature Review." *AMCIS 2013 Proceedings*.

Ludwig, T., Kotthaus, C., Reuter, C., Dongen, S. van, and Pipek, V. (2017). "Situated crowdsourcing during disasters: Managing the tasks of spontaneous volunteers through public displays." *International Journal of Human-Computer Studies*, Special Issue on Mobile and Situated Crowdsourcing, 102, 103–121.

Meier, P. (2013). "Human Computation for Disaster Response." *Handbook of Human Computation*, P. Michelucci, ed., Springer New York, New York, NY, 95–104.

Neubauer, G., Nowak, A., Jager, B., Kloyber, C., Flachberger, C., Foitik, G., and Schimak, G. (2013). "Crowdtasking – A New Concept for Volunteer Management in Disaster Relief." *Environmental Software Systems. Fostering Information Sharing*, IFIP Advances in Information and Communication Technology, J. Hřebíček, G. Schimak, M. Kubásek, and A. E. Rizzoli, eds., Springer Berlin Heidelberg, 345–356.

Orloff, L. (2011). *Managing Spontaneous Community Volunteers in Disasters: a field manual*. CRC Press.

Perry, R. W., and Lindell, M. K. (2003). "Understanding Citizen Response to Disasters with Implications for Terrorism." *Journal of Contingencies and Crisis Management*, 11(2), 49–60.

Reuter, C., Heger, O., and Pipek, V. (2013). "Combining Real and Virtual Volunteers through Social Media." *Proceedings of the 10th International Conference on Information Systems for Crisis Response And Management*, 11.

Reuter, C., Marx, A., and Pipek, V. (2011). "Social Software as an Infrastructure for Crisis Management - a Case Study About Current Practice and Potential Usage." *Proceedings of the 8th International Conference on Information Systems for Crisis Response And Management*, 10.

Rizza, C., and Pereira, Â. G. (2014). "Building a resilient community through social network: ethical considerations about the 2011 Genoa floods." *Proceedings of the 11th International Conference on Information Systems for Crisis Response And Management*, 6.

Rizza, C., Pereira, Â. G., and Curvelo, P. (2014). "'Do-it-Yourself Justice': Considerations of Social Media use in a Crisis Situation: The Case of the 2011 Vancouver Riots." *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)*, 6(4), 42–59.

Scanlon, J., Helsloot, I., and Groenendaal, J. (2014). "Putting It All Together: Integrating Ordinary People Into Emergency Response." *International Journal of Mass Emergencies and Disasters*, 32(1), 43–63.

Shaskolsky, L. (1965). "Volunteerism in disaster situations." 43.

Stallings, R. A., and Quarantelli, E. L. (1985). "Emergent Citizen Groups and Emergency Management." *Public Administration Review*, 45, 93.

Sutton, J., Palen, L., and Shklovski, I. (2008). "Backchannels on the Front Lines: Emergent Uses of Social Media in the 2007 Southern California Wildfires." *Proceedings of the 5th International Conference on Information Systems for Crisis Response And Management*, 9.

Taylor, M., Wells, G., Howell, G., and Raphael, B. (2012). "The role of social media as psychological first aid as a support to community resilience building." *Australian Journal of Emergency Management, The*, 27(1), 20.

Vieweg, S., Castillo, C., and Imran, M. (2014). "Integrating Social Media Communications into the Rapid Assessment of Sudden Onset Disasters." *Social Informatics*, 444–461.

Vieweg, S., Hughes, A. L., Starbird, K., and Palen, L. (2010). "Microblogging During Two Natural Hazards Events: What Twitter May Contribute to Situational Awareness." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, ACM, New York, NY, USA, 1079–1088.

Watson, H., and Finn, R. L. (2013). "Privacy and ethical implications of the use of social media during a volcanic eruption: some initial thoughts." *Proceedings of the 10th International Conference on Information Systems for Crisis Response And Management*, 5.

Wenger, D. E., Faupel, C. E., and James, T. F. (1985). *Disaster Beliefs and Emergency Planning*. Hazard Reduction and Recovery Center, College of Architecture, Texas A & M University.

Whittaker, J., McLennan, B., and Handmer, J. (2015). "A review of informal volunteerism in emergencies and disasters: Definition, opportunities and challenges." *International Journal of Disaster Risk Reduction*, 13(Supplement C), 358–368.

Wolensky, R. P. (1979). "Toward a Broader Conceptualization of Volunteerism in Disaster." *Journal of Voluntary Action Research*, 8(3–4), 33–42.

Yin, J., Karimi, S., Lampert, A., Cameron, M., Robinson, B., and Power, R. (2015). "Using social media to enhance emergency situation awareness:" *IJCAI International Joint Conference on Artificial Intelligence*, 2015-Janua, 4234–4239.

Zettl, V., Kotthaus, C., Ludwig, T., and Skudelny, S. (2017). "Embedding Unaffiliated Volunteers in Crisis Management Systems: Deploying and Supporting the Concept of Intermediary Organizations." *Proceedings of the 14th International Conference on Information Systems for Crisis Response And Management*, 11.

Sharing Incident and Threat Information for Common Situational Understanding

Bjørn Erik Munkvold
CIEM, University of Agder
bjorn.e.munkvold@uia.no

Jaziar Radianti
CIEM, University of Agder
jaziar.radianti@uia.no

Jan Ketil Rød
Norwegian University of Science and Technology
jan.rod@ntnu.no

Tomasz Opach
Norwegian University of Science and Technology / Linköping University
tomasz.opach@ntnu.no

Mikael Snaprud
Tingtun AS
mikael.snaprud@tingtun.no

Sofie Pilemalm
Linköping University
sofie.pilemalm@liu.se

Deborah Bunker
University of Sydney
deborah.bunker@sydney.edu.au

ABSTRACT

This paper presents the INSITU research project initiated to provide a systematic approach for effective sharing, integration and use of information from different sources, to establish a common operational picture (COP) and shared situational understanding among multiple actors in emergency response. The solution developed will provide an interactive map display, integrating harmonisation of terminology and collaboration support for information sharing and synthesis. The enhanced COP will also support evaluation and learning from exercises and incidents. The project involves close collaboration with emergency management stakeholders in Norway, for requirements analysis, participatory design, and validation of project deliverables. The research will improve information sharing and decision support in emergency operations centres, which will contribute to improve societal resilience through more effective response capability.

Keywords

Common operational picture, situational awareness, collaboration support, geographic information systems, terminology harmonisation.

INTRODUCTION

A recurring challenge in emergency response is to quickly be able to collect and integrate relevant information to form an initial shared understanding of a crisis situation, and to dynamically update a common situational picture of the evolving incident (Laakso and Palomäki, 2013). The core of this challenge is to be aware of the information needs of the collaborating partners, effectively share relevant and timely information to the right receivers, and similarly - to know what information is available to be requested (Petrenj et al., 2012). Evaluations from several incidents and large-scale exercises document challenges of ineffective information sharing between involved responders and lack of a common operational picture (COP) (e.g., Bunker et al., 2015; Steigenberger, 2016; Wolbers and Boersma, 2013).

While an increasing amount of digital information sources are available, the information landscape remains fragmented with lack of interfaces among the different sources and a varying data quality. Digital map services provide a key resource for developing a COP. However, the lack of standardisation of tools and symbols in use for crisis maps limits the possibility for integrated use for sharing incident and threat information across collaborating entities (JRCC, 2018). Further, as highlighted by the Norwegian Ministry of Justice and Public Defense (Stm. 10, 2016-2017), different terminology in use by the different responders for depicting the same concepts and events also represents a challenge for information sharing and shared situational understanding. Finally, there is currently limited support for visualising and sharing a COP as a basis for systematic learning from incidents and exercises.

On this basis, we have initiated a research project titled "Sharing Incident and Threat Information for Common Situational Understanding" (INSITU), funded by the Research Council of Norway. The goal of this project is to contribute to effective sharing, integration and use of available information from different sources, to establish a COP as a basis for shared situational understanding. Reaching this goal requires systematic analysis of current practices and needs for information sharing, developing suggested standards for map symbols and a common map-based interface, supporting harmonisation of crisis terminology, and developing methods and tool support for collaborative information synthesis. These research challenges are currently being addressed by an interdisciplinary team of experts in emergency management, information systems, geographic information science and systems (GIS), terminology harmonisation, and computer science. The project is led by the Centre for Integrated Emergency Management (CIEM) at University of Agder, Norway. Other academic partners are the Norwegian University of Science and Technology (NTNU), Department of Geography, the Center for Advanced Research in Emergency Response (CARER) at Linköping University, Sweden, and the Interoperability in Extreme Events Research Group, The University of Sydney Business School. The project consortium also includes two companies: Tingtun AS is a developer of methodology and software for terminology harmonisation, and One Voice AS is supplier of the leading crisis management system (CIM) in Norway. End user involvement is secured through the participation of the emergency preparedness office of the County Governor in Agder as a partner in the project, and there is a broad representation of core emergency management stakeholders in the project reference group.

To address the above-mentioned challenges, a core focus of this project is to strengthen the collaborative process in establishing a COP and shared situational understanding. This will include contributing to harmonisation and standardisation of crisis-related terminology and map support, and procedures for effective collection and sharing of relevant information. The INSITU project seeks to answer the following research questions:

- Which information elements are critical to share in scenarios involving collaboration between several emergency responders, and how and in what formats can this information be accessed?
- What are the perceived needs for harmonisation of terminology in use between the different responders, and how can such harmonisation be supported?
- How can geographic resources and interactive map-based interfaces be used more effectively to support collaboration and shared situational understanding, e.g. through standardisation of map symbols and functionality?
- Which method and tool support is required for effective synthesis and presentation of information from different sources, as a basis for common situational understanding and for evaluation and learning from incidents?

RELATED RESEARCH AND PRACTICE

While former research has provided important contributions in the form of concepts, architectures and tools for supporting situational awareness and COP (e.g., Cordeiro et al., 2015; Luokkala et al., 2017; Stiso et al., 2013; van Dijk, 2015), experience from practice shows that developing a shared situational understanding remains challenging. For example, the Norwegian National Forum for Exercises and Evaluation in 2018 hosted a seminar with Norwegian emergency responders for discussing current challenges in establishing a COP and shared situational understanding. Among the barriers discussed here were inefficient information sharing due to lack of knowledge on the information needs of the different response organisations, and problems with interoperability of existing support technologies being used by the different responders. The responders agreed that rather than aiming for developing a joint, national COP supporting different scenarios, what is needed is an information infrastructure supporting COPs for specific scenarios that can be adapted to the context of the local emergency responders.

Bunker et al. (2015) discuss how existing solutions for supporting a COP are not able to represent "the range of perspectives, options, facets and changes that often challenge responders" (p. 52). Further, there is currently no

universally agreed upon definition of a COP. The International Forum to Advance First Responder Innovation (IFAFRI, 2018) also lists as one of four capability gaps the first responders' ability to collect data from traditional (e.g., weather maps, sensor readings) and nontraditional (e.g., social media) information sources and integrate this data into a user-configurable COP.

As an illustration of the problem, according to the rescue services personnel working at command and control level during the extensive forest fires in Sweden in summer 2018 a major challenge inhibiting fast decision-making and response was the lack of digital maps and other digital tools, e.g. for information sharing and weather forecasts. Thus, the Swedish rescue services had to rely on whiteboards with information and forecasts that quickly became outdated.

The INSITU project focuses on three core elements in supporting a common situational understanding: 1) integrated map services; 2) harmonisation of terminology; and 3) collaboration support for information sharing. A brief status on knowledge in these three areas is presented here.

Integrated Map Services

As documented in the recently published Handbook for the Norwegian Rescue Services (JRCC, 2018), no common norm exists for map support among the different first responders and public emergency stakeholders. A range of different "platforms" for map services is currently in use (e.g., ArcGIS, Avinet, Basecamp, GIS-link, Locus TransMed, Locus TransFire, Terra and Vision). However, interviews with emergency responders show that none of these services are considered to fully cover their needs. Furthermore, the use of symbols and colours is not fully standardised, and good drawing functionality is not fully incorporated. There are also local variations in the services utilised within each sector. This limits the possibilities for effective information sharing based on a common map interface, and points to a need for more standardisation of map support that also allows for integrating data from different sources (JRCC, 2018).

While formalised map symbol standards for emergency contexts do exist, these have not been widely adopted by map providers (Robinson et al., 2013). A main goal for map displays is to design effective representations of spatial information using cartographic symbols. Ideally, all users should understand the symbols correctly, quickly, and identically, but this is not always the case. Further problems arise when map users are unable to spend time referring to a legend during the map reading process because the map is used in an emergency situation where response time is critical (Akella, 2009).

A change is needed to encourage the standardisation of symbols for emergency response, and future maps for emergency management must be better adapted to individual user groups. As agencies are obligated to collaborate in their operational practice and emergency scenarios during crisis incidents such as industrial hazards or flooding, an extensive understanding of common scenarios is required to equip a COP map display with adequate and efficient interactive functions. The functions, on the one hand, must efficiently support expert users in their operational tasks, and, on the other hand, cannot make users confused with their multiplicity and complexity. Thus, our research will focus on map usability in both map content and visual controls to make map use more intuitive.

Harmonisation of Crisis Management Terminology

The need for harmonisation of terminology among crisis responders has been recently highlighted (JRCC, 2018). As an example of this challenge, there are at least four different Norwegian terms for an incident site ("åsted", "fareområde", "skadested", "tiltaksområde"). In addition, we have sectorial abbreviations for locations related to an incident site.

This problem is not specific for Norway. Snaprud et al. (2016) have explored the availability of crisis vocabularies in several countries and found that if such resources exist they are generally scattered on different websites, represented in different formats and forms, and not harmonised across sectors.

Examples of resources on process and methodology for terminology harmonisation that we might build on in the INSITU project include: Terminology work - Harmonisation of concepts and terms (ISO 860:2007) and ISO 22300:2018 Security and Resilience – Vocabulary.

Collaboration Support for Shared Situational Understanding

Challenges of effectively sharing information across organisational boundaries for managing emergency situations have been documented in several studies (e.g., Laakso and Palomäki, 2013; Ley et al., 2014). An ethnographic study of disaster exercises in the Netherlands (Wolbers and Boersma, 2013) documents how the coordination process was distorted by the emergent management professionals attributing different meanings to

information. They thus conclude that "information management during emergency response operations is about interpreting information and negotiating its relevance for different professions" (p. 195). Barriers to effective cross-agency communication and information sharing have also been reported in disaster healthcare (Abbas et al., 2018). The related efforts of specifying minimum data sets of essential data elements to be exchanged among the agencies are clearly relevant for our project.

Existing procedures for situational reports provided by the Norwegian Directorate for Civil Protection specify the communication structures and actors involved. However, they do not provide detailed guidelines concerning what specific information elements to share, where to find them, and how to best synthesise and present this information. Research in the area of collaboration engineering focuses on how to develop detailed, easy to use 'scripts' for effectively conducting collaborative processes without a trained facilitator (de Vreede et al., 2009). These collaboration scripts also specify the use of relevant digital tools, and provide support for inter-disciplinary teams in effectively processing and making sense of available information (Lazareva and Munkvold, 2017). In the domain of emergency response, the use of collaboration scripts has been demonstrated to support situational awareness (Appelman and van Driel, 2005).

Finally, there is currently also a lack of shared resources for supporting systematic learning from exercises. Being able to use a COP and an integrated map-based interface also in the evaluation phase, would represent a major improvement in practice.

RESEARCH APPROACH

As depicted in Figure 1, the INSITU project will apply a combination of research methods for addressing the three focal areas in the project as presented in the previous section.

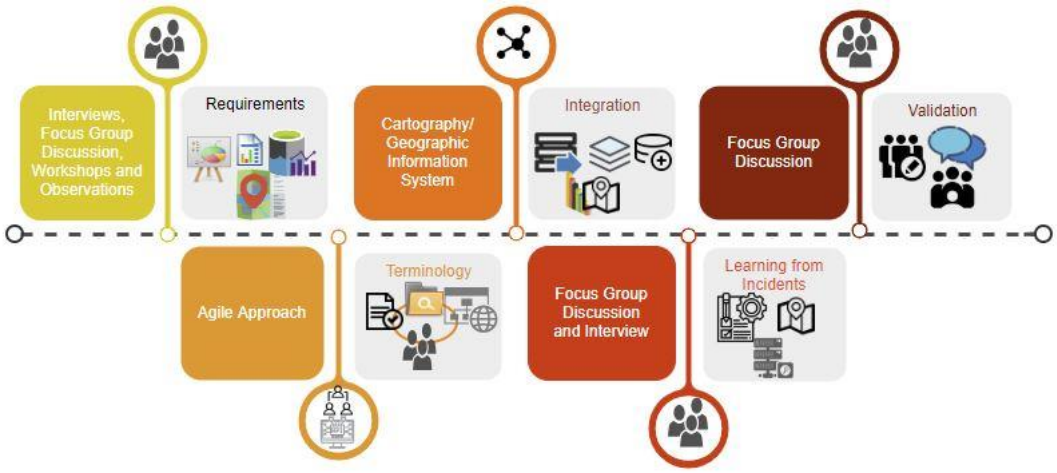


Figure 1. Combined Research Approach

The initial *requirements gathering* will be conducted through focus group discussion (FGD), literature review, document analysis, workshops for requirements elicitation and prioritisation, and observation of emergency exercises. This task will focus on identifying the critical information elements needed to be shared between the involved stakeholders, what information sources are currently being used, and the format of the relevant information. This analysis will explore different types of threats and incidents, as caused by both natural and man-made hazards. The analysis will also consider additional information sources that are not already used, such as sensor data and social media data. Processing such data will then require use of methods for real-time detection, filtering and classification, based on natural language processing, machine learning and visual analytics (Reuter et al., 2018). This task will also scrutinize possible security concerns involved in sharing information between different responders. This will form the basis for design recommendations for a harmonised terminology and standard map symbols and the integration of these in a common map interface. An agile approach will be used, working together with end users in a participatory design process (Sanders et al., 2010), and collecting their feedback throughout the development process.

The methodology for *harmonisation of terminology* will combine a participatory process with a quantifiable justification process as a basis for selecting terms to be included in a common vocabulary. The idea is to compute a justification score for each term as input to the harmonisation discussions. The justifications will include references to external definitions of a concept in a law, regulation, standard, guideline or other prominent

references. The sources of references and possible weights for them will be tested and agreed with the users in the participatory design process. The harmonisation will address both the form and the content of the terminologies. The form will cover how to represent the terminology from the metadata describing it, the terms and their properties including attributes and classifications.

Concerning *integration*, the aim is to integrate various interactive displays into one, consistent map-based interface facilitating shared situational understanding in the different phases of an incident. The resulting interactive tool support will provide users with a map display featuring switchable thematic layers showing standardised cartographic symbols representing critical information elements. The symbols will be retrieved from a shared data repository that is to be designed as a project deliverable. Of critical importance in this task is to avoid sharing irrelevant information that may lead to information overload. Literally, a map-based interface cannot be visually cluttered by a multiplicity of point, line, and area symbols, and at the same time it cannot be overloaded by too many interactive functions. Therefore, the interactive tool support will be developed through a sequence of proof of concept implementations accompanied by rapid prototype assessments with target users, in order to test combinations of various map symbols with particular interactive functions.

Complementing the integrated map support for COPs, the project will develop collaborative scripts detailing information management procedures for collecting, sharing and synthesising information from different sources. These collaborative scripts will specify required information elements, the sources for these elements and how to access them, the procedure for sharing information with other stakeholders (including formats and tools), and how to effectively combine the information elements to support situational understanding. The collaborative scripts will be presented through an interactive, easy-to-use, web interface.

For developing enhanced support for systematic *learning from incidents*, a combination of focus group discussions, review of incident report studies, and After Action Reviews will be conducted. This task will address the need for common information sources supporting systematic learning from exercises and incidents. The integrated terminology, map and collaboration support will be adapted for this purpose. In addition, the possibility of adding functionality for recording and playing back event handling in the common map-based interface will be analysed.

The process for *validation* of project deliverables will be conducted iteratively throughout the project, using process walk-throughs for all project outcomes in workshops, questionnaires, field trials in relevant exercises, and validation in a simulated, realistic environment provided by one of the project partners in the form of an experimental control room facility for crisis management training and tool testing.

PRACTITIONER INVOLVEMENT

As outlined in the previous section, the participatory design process applied in the INSITU project requires close interaction with emergency management practitioners from the initial requirements elicitation to the validation of project deliverables. This involves authorities and associations both at the national and regional level.

Examples of organizations that so far have confirmed their participation in the project reference group include:

- Norwegian Directorate for Civil Protection
- Norwegian Police Directorate
- Norwegian Communications Authority
- Norwegian Radiation and Nuclear Safety Authority
- Norwegian Water Resources and Energy Directorate
- Norwegian Mapping Authority
- Norwegian Public Roads Administration
- Norwegian Defence University College
- Norwegian Fire Protection Association
- Norwegian Fire Academy
- Norwegian Council for Search and Rescue
- The Joint Rescue Coordination Centre, Southern Norway
- Barentswatch (Centre for the Sharing of Sea and Coastal Information)
- The Society of Voluntary Search and Rescue Organisations
- The Language Council of Norway

This broad representation is required for being able to develop useful support for information sharing and collaboration that caters for the needs of the organisations involved. Also, the list demonstrates the shared view on the importance of the research questions addressed in the INSITU project, and provides a good basis for the uptake of the project deliverables among the practitioners.

CONCLUSION

The research presented in this paper will contribute to strengthen the overall resilience of society by providing methods and tool support for developing common situational understanding among different emergency management sectors and units. The INSITU project will develop knowledge that addresses critical shortcomings in today's practice, regarding harmonisation of terminologies in use and interoperability and standardisation of map resources. By this, the project will contribute to improved preparedness, response and learning from experience. Through broad involvement of key crisis management stakeholders in Norway, the project will facilitate knowledge development on practices in the different sectors and increased understanding of the information needs for the tasks and roles involved. The software tools developed and adapted in the project will provide easy access to a harmonised terminology and common map support, for being included in COPs, training material and procedures for inter-sectoral communication and collaboration.

The INSITU project is based on an interdisciplinary perspective, building on knowledge from multiple, related research areas including situational awareness and COP, collaboration engineering, terminology management, GIS and crisis mapping, and human-information interaction. The project will also contribute new knowledge in these domains, through combining harmonised terminology, standardised map support and collaboration scripts for information sharing and synthesis, in an integrated solution for enhanced situational understanding.

ACKNOWLEDGEMENTS

The INSITU project is funded by the Research Council of Norway. We thank the reviewers and Track Chairs for their constructive comments.

REFERENCES

Abbas, R., Norris, A. C. and Parry, D. T. (2018) Pinpointing what is wrong with cross-agency collaboration in disaster healthcare, *Journal of the International Society for Telemedicine and eHealth*, 6, 1, e3, 1-10.

Akella, M. K. (2009) First Responders and Crisis Map Symbols: Clarifying Communication, *Cartography and Geographic Information Science*, 36, 1, 19-28.

Appelman, J. H. and van Driel, J. (2005) Crisis-response in the Port of Rotterdam: can we do without a facilitator in distributed settings?, *Proceedings of the 38th Hawaii International Conference on System Sciences*, IEEE.

Bunker, D., Levine, L. and Woody, C. (2015) Repertoires of collaboration for common operating pictures of disasters and extreme events, *Information Systems Frontiers*, 17, 51-65.

Cordeiro, K. F., Campos, M. L. M. and Borges, M. R. S. (2015). aDApTA: Adaptive approach to information integration in dynamic environments, *Computers in Industry*, 71, 88-102.

de Vreede, G. J., Briggs, R. O. and Massey, A. P. (2009) Collaboration engineering: foundations and opportunities, *Journal of the Association for Information Systems*, 10, 121-137.

IFAFRI (2018) Capability Gap 4 "Deep Dive" Analysis Synopsis. The International Forum to Advance First Responder Innovation, August 2018.

JRRC (2018) *Håndbok for redningstjenesten (Handbook for the Norwegian Rescue Services)*. The Joint Rescue Coordination Centres, Norway. Available from https://www.hovedredningssentralen.no/wp-content/uploads/2018/09/Den-norske-redningstjenesten.pdf [last accessed March 22, 2019]

Laakso, K. and Palomäki, J. (2013) The importance of a common understanding in emergency management, *Technological Forecasting & Social Change*, 80, 9, 1793-1713.

Lazareva, A. and Munkvold, B. E. (2017) Facilitating Collaboration: Potential Synergies Between Collaboration Engineering and Computer-Supported Collaborative Learning, *International Journal of e-Collaboration*, 13, 3, 22-36.

Ley, B., Ludwig, T., Pipek, V., Randall, D., Reuter, C. and Wiedenhoefer, T. (2014) Information and Expertise Sharing in Inter-Organizational Crisis Management, *Computer Supported Cooperative Work*, 23, 4-6, 347-387.

Luokkala, P., Nikander, J., Korpi, J., Virrantaus, K. and Torkki, P. (2017) Developing a concept of context-aware common operational picture, *Safety Science*, 93, 277-295.

Petrenj, B., Lettieri, E. and Trucco, P. (2012) Towards enhanced collaboration and information sharing for critical infrastructure resilience: current barriers and emerging capabilities, *International Journal of Critical Infrastructures*, 8, 2/3, 107-120.

Reuter, C., Hughes, A. L. and Kaufhold, M.-A. (2018) Social Media in Crisis Management: An Evaluation and Analysis of Crisis Informatics Research, *International Journal of Human-Computer Interaction*, 34, 4, 280-294.

Robinson, A. C., Pezanowski, S., Troedson, S., Bianchetti, R., Blanford, J., Stevens, J., Guidero, E., Roth, R. E. and MacEachren, A. M. (2013) Symbol Store: sharing map symbols for emergency management, *Cartography and Geographic Information Science*, 40, 5, 415-426.

Sanders, E. B. N., Brandt, E. and Binder, T. (2010) A framework for organizing the tools and techniques of participatory design, *Proceedings of the 11th Biennial Participatory Design Conference*, Sydney, Australia, ACM, 195-198.

Snaprud, M. H, Radianti, J. and Svindseth, D. (2016) Better Access to Crisis Terminology, *Information Technology in Disaster Risk Reduction (ITDRR) Conference*, IFIP TC5, Sofia, Bulgaria.

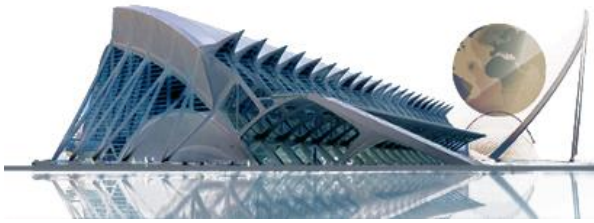
St. Meld. 10 (2016-2017). *Risk in a Safe and Secure Society*. Report to the Storting (white paper), Norwegian Ministry of Justice and Public Security. Available from https://www.regjeringen.no/en/dokumenter/meld.-st.-10-20162017/id2523238/ [last accessed March 22, 2019].

Steigenberger, N. (2016) Organizing for the Big One: A Review of Case Studies and a Research Agenda for Multi-Agency Disaster Response, *Journal of Contingencies and Crisis Management*, 24, 2, 60-72.

Stiso, M. E., Eide, A. W., Halvorsrud, R., Nilsson, E. G. and Skjetne, J. H. (2013) Building a flexible common operational picture to support situation awareness in crisis management, *Proceedings of the 10th International ISCRAM Conference*, Baden-Baden, Germany.

van Dijk, H. (2015) Situation Awareness in Crisis Situations: Development of a User Defined Operational Picture, *Proceedings of the 12th International ISCRAM Conference*, Kristiansand, Norway.

Wolbers, J. and Boersma, K. (2013) The Common Operational Picture as Collective Sensemaking, *Journal of Contingencies and Crisis Management*, 21, 4, 186-199.



ISCRAM 2019

16 TH INTERNATIONAL CONFERENCE ON INFORMATION SYSTEMS FOR CRISIS RESPONSE AND MANAGEMENT

Posters & Demos

Chairs,

Josune Hernantes, *Tecnun, University of Navarra, Spain*

Leire Labaka, *Tecnun, University of Navarra, Spain*

Towards proactive agility of crisis response

Anne-Marie Barthe-Delanoë
Laboratoire de Génie Chimique,
Université de Toulouse, CNRS, INPT, UPS,
Toulouse, France
annemarie.barthe@ensiacet.fr

Audrey Fertier
Centre de Génie Industriel,
IMT Mines Albi,
Albi, France
audrey.fertier@mines-albi.fr

INTRODUCTION

The goal of this poster is to introduce the very first steps of a framework to support decision-making during the crisis response step of the crisis lifecycle. Indeed, crisis situations are unstable phenomena by nature and by the effects of the crisis response itself. So, the crisis response is challenged over time: new objectives, new risks, lack of resources, evolving weather conditions, etc. Reacting once events happened to adapt the response is not sufficient enough to provide the agility required by the decision-makers.

Based on the projected effects of the chosen crisis response on a real-time model and several anticipated models of the situation, the proposed framework aims to achieve the last step of the situation awareness approach: the projection of the current situation in the near future. This can enable a proactive on-the-fly agility of the crisis response. The presented idea relies on the main results of the previous research work of two research teams on the agility of the crisis response (Barthe-Delanoë et al. 2018) and the transformation of raw data into a Common Operational Picture (COP) in a context of Big Data (Fertier et al. 2018). The aim is to combine these results to achieve the highest level of situational awareness by supporting proactive agility of the crisis response instead of reactive agility.

METHODOLOGY AND PROPOSAL

Based on a model-driven and event-driven approach, two models of the crisis situation are designed, describing the current situation from two different points of view:

- The *expected model* M_E that depicts the planned and expected situation at time *t* (i.e. what it is expected with respect to the executed actions planned into the crisis response).
- The *field model* M_F that represents the real situation model of the collaboration at time *t*. It can be understood as the ground truth model.

The chosen crisis response is projected on M_E leading to one model with the expected outcomes, called the projected expected model M_{Ep} (as shown on Figure 1), into a reasonable time window until a projected time t_p. The same is done on M_F but with additional variability (regarding weather conditions, traffic, etc.), leading to several models of the envisioned crisis situation, called the projected field models M_{Fp}. To this end, the states of the elements composing the model of the current situation are projected in the near future: partners, services, environment, dangers, risks, etc.

Trends, forecasts and models are crucial to support the proactive agility in order to perform the projection of events and actions: the system can use the combination of weather forecasts, traffic flow models (Poole and Kotsialos 2016), atmospheric dispersion models (Wang et al. 2015), crowd movement models, etc. to feed the projected models. The choice of the relevant simulation models depends on the nature and the location of the crisis: road crisis, chemical plant accident, major flood, hazardous material release etc.

The idea of proactive agility relies on the calculation of the projected distance, named $\partial_p(t_p)$, between these models. The systemic difference between the projected expected and field models can be calculated, through an adapted tree-edit distance algorithm to detect and analyze significant changes. The difference ∂_p between the states depicted into M_{Ep} and one of the M_{Fp} is quantified as shown on Equation 1:

$$\partial_p(t_p) = \sum_{i=1}^{n}(\partial_i(t_p) * w_i) \quad \text{(Equation 1)}$$

Where:

- w_i is the edit distance cost (create, update, delete) of an element from the expected projected model M_{Ep} (compared to the studied projected field model M_{Fp}) regarding its nature (risk, partner, etc.); $w_i \in \mathbb{N}^*$.
- $\partial_i(t_p)$ is the weight of the element. It represents the importance rank between elements of a same nature, and it is a function of time; $\partial_i \in \mathbb{R}$ and $0 \leq \partial_i \leq 1$

∂_p evolves over time and can be represented as a function of time. The greater the distance, the less relevant the crisis response. In the case where ∂_p exceeds a given threshold ∂_t, it means that the crisis response should be adapted. Thus, the objective of the distance is to assess the stability of the proposed crisis response regarding the uncertainty and the changes of the context over time. This would support decision-makers in choosing the best response candidate.

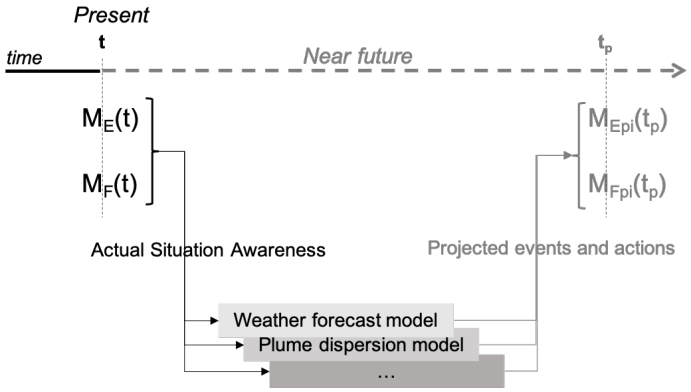


Figure 1. Using forecasts and simulation models to feed projected expected and field models.

CONCLUSIONS AND FURTHER WORK

In this poster, an improvement of the Agility Service for crisis response proposed in (Barthe-Delanoë et al. 2018) is presented. It is defined to provide a proactive agility and thus achieving the third step of the situational awareness: the projection of the future states and events. This improved framework will enable to detect future crisis evolutions based on the forecast of future events and the monitoring of the ongoing process activities.

The main idea is to assess if the ongoing crisis response is still relevant given the current situation and the current response process. To this purpose, anticipation is introduced through the detection of potential gaps using projected models, and the simulation of the effects of the proposed adaptation over time.

Further issues to address are: (i) dealing with the number of projected models (how to choose the set of crisis and environment variables and their combinatory); (ii) dealing with data integration to feed the models with a Complex Event Processing engine: raw data from the ground as well as data coming from simulation tools, forecast models, etc.; (iii) analyzing the performance of the whole solution.

REFERENCES

Barthe-Delanoë, A.-M., Montarnal, A., Truptil, S., Bénaben, F., and Pingaud, H. (2018). "Towards the agility of collaborative workflows through an event driven approach–Application to crisis management." *International journal of disaster risk reduction*, 28, 214–224.

Fertier, A., Montarnal, A., Barthe-Delanoë, A.-M., Truptil, S., and Bénaben, F. (2018). "Reducing Information Load to Enhance Collaborative Awareness Thanks to a Pre-selection of Information." *Collaborative Networks of Cognitive Systems*, IFIP Advances in Information and Communication Technology, L. M. Camarinha-Matos, H. Afsarmanesh, and Y. Rezgui, eds., Springer International Publishing, Cardiff, UK, 286–294.

Poole, A., and Kotsialos, A. (2016). "Traffic Flow Model Validation Using METANET, ADOL-C and RPROP." *IFAC-PapersOnLine*, 14th IFAC Symposium on Control in Transportation Systems CTS 2016, 49(3), 291–296.

Wang, Y., Huang, H., and Zhu, W. (2015). "Stochastic source term estimation of HAZMAT releases: algorithms and uncertainty." *Proceedings of the 12th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2015)*, Kristiansand.

The Search for Embeddedness: Leveraging Scientific Modeling in Disaster Response

Theresa Jefferson
Loyola University Maryland
tljefferson@loyola.edu

John R. Harrald
Virginia Tech
jrharrlad@gmail.com

INTRODUCTION

Numerous studies concerning the response to extreme events demonstrate serious management, coordination, and problem-solving issues that diminished the ability to minimize human suffering. A plethora of scientific modeling technologies exist that can aid in both the panning and response to disasters. In fact, the availability of scientific models is accelerating – but the ability to adopt this technology has had a much slower growth pattern. This research focuses on determining methods for appropriating, integrating and using scientific modeling technologies to improve disaster response efforts in the area of mas care. This work will build on previous research concerning the modeling of technology embeddedness.

METHODOLOGY

This research investigates the reasons that emergency managers, in disaster response environments, under-utilize scientific modeling technologies. The goal is to provide guidance to increase the utilization of the technologies.

This research aims to address the question: *Can an embeddedness model (Figure 1) provide insight on why emergency managers under-utilize scientific modeling technologies for disaster response?*

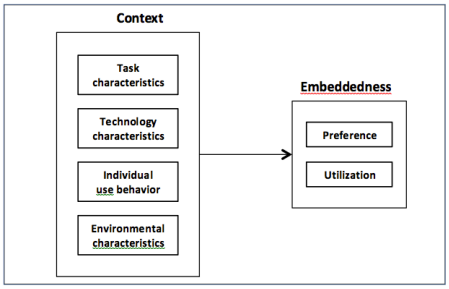


Figure 1. Model of Technology Embeddedness (Phillips-Wren and McKniff, 2015)

The proposed model portrays embeddedness of technology as a function of Preference and Utilization. In order for emergency managers to rely on scientific modeling technology it is necessary that they trust in the technology. This study conceptualizes trust and the interaction between the emergency manage and the technology (Dix et al. 2005) as preference. Preference portrays the emergency manager's desire to use the technology to undertake a task. In this research, preference describes the emergency managers feelings of trust and personal familiarity with the scientific modeling software. Utilization is the degree of use of the technology to accomplish a goal. In the proposed model the emergency manager and the scientific modeling technology work together to respond to the disaster.

The proposed model shows that Context is a pre-condition to embeddedness. By integrated the Extended Technology Acceptance Model (UTAUT) and the Task-Technology-Fit Model, Context can be characterized by four constructs: Task Characteristics, Technology Characteristics, Individual Use Behavior, and Environmental Characteristics (Phillips-Wren and McKniff). A goal of this research is to fully define these four constructs in terms of a disaster operations environment. Emergency managers are focused on making decisions to minimize the impacts of a disaster on the human and built environment. This research focuses particularly on decisions

regarding mass care. Therefore, the task characteristics involve the ability for the modeling technology to align with the decisions regarding mass care and to contribute in a meaningful way toward the accomplishment of response efforts. Technology characteristics concern the reliability of the software/hardware, availability and flexibility to accomplish the task, and ease of use. Individual use behavior concerns the individual's willingness to use the technology and their knowledge concerning appropriate usage. Environmental Characteristic refers to appropriate training, organization adoption, and culture, concerning the use of scientific modeling technologies.

The related, more detailed questions that can be extracted from exploration of the proposed embeddedness model include:

- *What causes individuals to reject the use of scientific modeling technologies?*
- *What are the impediments to emergency mangers using scientific modeling technologies for disaster response?*
- *What are the characteristics of the disaster context that influence the use of scientific modeling technologies for disaster response?*

The end objective is to provide insights that will allow emergency managers to harness the capability that scientific modeling technology provides to improve decision making in the complex and chaotic disaster response environment.

Results

The first phase of this research has involved the formulation of a methodology for studying the under-utilization of scientific modeling technologies in disaster response. This study will use an exploratory case study approach. This approach is beneficial when studying events occurring within a fairly structured environment and can be used to make inferences as to why certain occurrences happen (Yin 2003; Shanks and Bekmamedova 2012). This research is primary exploratory.

This research will use data collected through both semi-structured interviews and surveys of emergency managers. Specifically, information concerning individual use, along with task, technology, and environmental characteristics will be gathered regarding the use of scientific modeling tools identified by a federal interagency effort led by FEMA and the Modeling and Data Working Group (MDWG) (US Department of Homeland Security, 2016). Initial work has involved coordination with the Talbot County Department of Emergency Management (Maryland, USA).

Currently, this research is in Phase 1. We have begun developing the questionnaire that will be used in the interview process. In addition, we are in the process of identifying subjects.

CONCLUSION

The focus of this research is not developing new technology but instead determining methods for appropriating, integrating and using candidate technologies to respond to an extreme event. It involves the evaluation of scientific modeling technologies to enable the decision making necessary in this often-chaotic environment. Initial tasks have involved a survey of current scientific modeling available for emergency management, the development of research objectives and the development of a methodology. The goal of this study is to provide guidance to increase the use of modeling technologies.

REFERENCES

Dix, A., Finlay, J., Abowd, Gl, and Beale, R. (2005) *Human Computer Interaction*, accessed on June 20, 2016, from http://fit.mta.edu.vn/files/DanhSach/__Human_computer_interaction.pdf.

Phillips-Wren, G., and McKniff, S. (2015) Beyond Technology Adoption: An Embeddedness Approach to Reduce Medication Errors. *Journal of Organizational Computing and Electronic Commerce*, 25, 2, 213-232.

Shanks, G. and Bekmamedova, N. (2012) Integrating Business Analytics Systems with the Enterprise Environment: An Evolutionary Process Perspective, *Fusing Decision Support Systems into the Fabric of the Context* (A. Respicio and F. Burstein, eds.), IOS Press, The Netherlands, 161- 172.

U.S. Department of Homeland Security, (n.d.). *ESFLG: Modeling and Data Inventory*, accessed on July 25, 2016, from http://gis.fema.gov/Model-and-Data-Inventory/index.html.

Yin, R. (2003). *Applications of Case Study Research,* Second Edition, Sage Publications, Inc., Thousand Oaks, CA.

LETSCROWD: Dynamic Risk Assessment for Mass Gatherings

Carlo Dambra
ZenaByte s.r.l.
carlo.dambra@zenabyte.com

Alex Gralewski
PROPRS Ltd.
alex.gralewski@proprs.com

Jordi Arias
ETRA I+D S.A.
jarias.etraid@grupoetra.com

INTRODUCTION

Risks for crowd in mass gathering events are so called "High Impact Low Probability" risks (e.g. terrorism, lone wolfs, domestic extremisms) and therefore managing them accordingly, i.e. without a sufficient statistics, means to "*seek a method that leads us to make the least egregious errors in decision-making across the range of possible scenarios that might develop in the future*" (Willis, et al., 2005). Thus, the LETSCROWD project proposes an innovative **Dynamic Risk Assessment** (**DRA**) methodology for Law Enforcement Agencies (LEAs) to assess risks for the crowd on the basis of dynamically collected information to minimise decision-making errors across the possible scenarios that might develop in the critical time frame from the event planning to the event execution.

METHODOLOGY

The proposed methodology is inspired by the network Intrusion Detection Systems (IDS) approaches as those proposed by (Chakir, et al., 2017) based on the analysis of Weak Signals (WS). A WS can be defined as (Schoemaker & Day, 2009) "*a disconnected piece of information that at first appears to be background noise but can be recognized as part of a significant pattern by connecting it with other pieces of information*".

WSs can be detected by different sensors detecting threat precursors: from humans as sensors (e.g. policemen in crowd or a citizen call to 112) to CCTV-based systems, from Cyber-Threat Intelligence systems to physical sensors (e.g. explosive detectors). Each received WS has a **Significance** (**S**) value assigned to it that is a linear weighted combination of the **Credibility** of the sensor in detecting the considered precursor, the **Reliability** of the detection and the **Time Distance** from the event (a speeding car can be considered differently if it is happening 3 days before the event or during the event), where S(WS)∈ [0, 1]. Moreover, each WS has metadata (geolocation, time, etc.) characterising it.

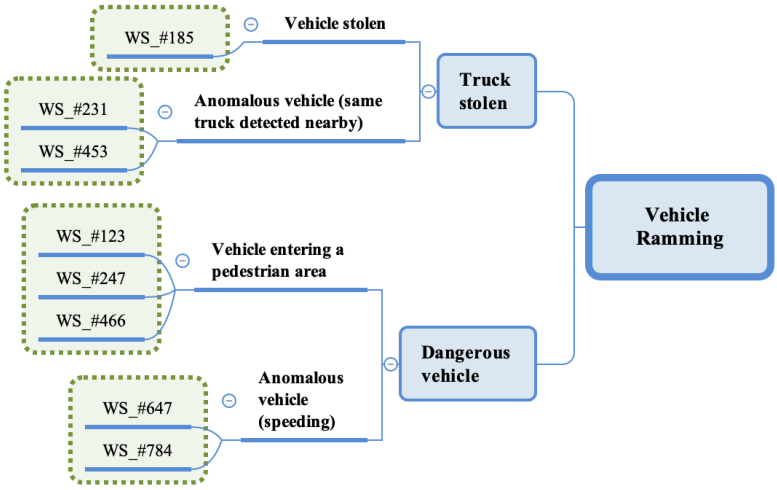


Figure 1 - An example of SP clustering

A WS alone could be insignificant, but when put in combination with other WS could become important. Thus, DRA uses the following mechanisms to group 2 or more WSs into a so-called **Suspicious Pattern** (**SP**) (see an example in Figure 1):

1. A priori, using the LEAs' knowledge through the application **rules** of type (IF conditions THEN grouping). Clearly rules are specific to each LEA and to the identified threats.
2. Dynamically, using an **automatic grouping** of WSs using logic similar to those currently used, for example, at some airport security checks: 3 or more credible WSs "**simultaneously**" happening in space or time from different sources of information can be grouped into a SPs.
3. Dynamically, using **data analytics** - applied on all received WS to generate suspicious pattern. Recently, researchers (Hasan, et al., 2016) started to publish deep learning techniques to automatically learn high-level representations, and then avoid the requirement of domain experts in designing features.

Each SP inherits significance from contributing WSs according to Certainty Factors theory (Lucas, 2001). In case of 2 WSs, with significance S_1 and S_2 respectively, significance of SP is derived using the following formula

$$S(S_1\ and\ S_2) = S_1 + (1 - S_1) * S_2$$

Having more than 2 WSs contributing to the same SP, it is possible to iteratively apply the proposed formula as follows (in case of 3 WSs with Significance S_1, S_2 and S_3, respectively):

$$S_{1\ and\ 2} = S(S_1\ and\ S_2) = S_1 + (1 - S_1) * S_2$$

$$S_{1\ and\ 2\ and\ 3} = S(S_{1\ and\ 2}\ and\ S_3) = S_{1\ and\ 2} + (1 - S_{1\ and\ 2}) * S_3$$

RESULTS

DRA has been integrated in the LETSCROWD Server (LS) developed by ETRA that incorporates also a policy making toolkit and crowd evacuation modelling tools. LS uses the trending Web technologies and receives info from external modules (web crawling, crowd info and multimedia suspicious behaviour detection) using REST technology. SPs above a selected Significance threshold are brought to the attention of the operator together with the attached multimedia information (e.g. a snapshot of the scene, a picture of the suspicious person) and related metadata to allow a risk-aware decision-making process.

CONCLUSIONS AND FURTHER WORK

The proposed approach is going to be tested and verified using data collected during mass gatherings events in Bilbao by Ertzaintza.

DRA methodology has the following advantages over more traditional approaches:

- It searches for **out-of-the-ordinary behaviours** and unseen threats;
- It allows **memory of hypotheses** and data rejected by security analysts and notices what **analysts are watching and asking**.

Finally, the proposed DRA approach is fully in line with the European Security Model (Council of the European Union, 2010) that prescribes, amongst other guidelines, *"… stronger focus on the **prevention of criminal acts** and terrorist attacks before they take place can help reduce the consequent human or psychological damage, which is often irreparable*" and "***Guidelines for hazard and risk-mapping methods, assessments and analyses** should be developed as well as an overview of the natural and man-made risks that the EU may face in the future.*"

ACKNOWLEDGMENTS

This work has received funding from the EU H2020 project LETSCROWD "Law Enforcement agencies human factor methods and Toolkit for the Security and protection of CROWDs in mass gatherings" (GA no. 740466).

REFERENCES

Chakir, E., Moughit, M. & Khamlichi, Y., 2017. *A Real-Time Risk Assessment Model for Intrusion Detection Systems.* s.l., International Conference on Information Technology and Communication Systems.

Council of the European Union, 2010. *Internal security strategy for the European Union - Towards a European Security Model.* s.l.:General Secretariat of the European Council.

Hasan, M. et al., 2016. *Learning temporal regularity in video sequences.* Las Vegas, 29th IEEE Conference on Computer Vision and Pattern Recognition (CVPR).

Lucas, P. J. F., 2001. Certainty-factor-like structures in Bayesian belief networs. *Knowledge-Based Systems*, Volume 14.

Schoemaker, P. J. H. & Day, G. S., 2009. How to Make Sense of Weak Signals. *MIT Sloan Management Review*, 50(3).

UK Government Office for Science, 2011. *Blackett Review of High Impact Low Probability Risks,* s.l.: s.n.

Willis, H., Morral, A., Kelly, T. K. & Medby, J., 2005. *Estimating Terrorism Risk,* s.l.: RAND Corporation - Center for Terrorism Risk Management Policy.

Xu, D. et al., 2015. *Learning deep representations of appearance and motion for anomalous event detection.* s.l., BMVC.

Comparative Study of Feature Representations for Disaster Tweet Classification

Pallavi Jain, Bianca Schoen-Phelan, Robert Ross
School of Computer Science
Technological University Dublin, Kevin Street, Dublin, Ireland
{pallavi.jain, bianca.phelan, robert.ross}@dit.ie

INTRODUCTION

Twitter is a popular social media platform where users publicly broadcast short messages on a myriad of topics. In recent years it has enjoyed an increased usage around disaster events due to availability of information in near real time. Additionally, enhanced information representations to facilitate the classification of social media in terms of relevancy and type of information is currently a highly active research area **(**Ashktorab et al., 2014, Imran et al., 2014, Win et al., 2018). In this work we consider the usefulness and reliability of a range of representation models in the analysis of disaster related social media.

EXPERIMENT DESIGN

In order to assess the effectiveness of individual feature representations, we examine the performance of a classification task when applied to labelled tweets on two levels: first, on the basis of informativeness, and then on the basis of type of information. We used a total of 15 twitter datasets of different disasters where 6 datasets are taken from CrisisLex (Olteanu et al., 2014) and 9 datasets are taken from Crisis NLP (Imran et al., 2016). Each dataset consist of data labelled according to informativeness of the tweet on the particular event, and according to type of information of tweet. Pre-processing was applied to the dataset. Hashtags, URLs, punctuation, emoticons, special characters, and stop words, such as 'the' and 'a', were all stripped from the data. Also we used unigram, hybrid unigram and bigram features to add word to word relation features and part of speech (POS) tagging, which results in syntactic behavior of words (Schütze, 1995). We used the Gensim phrase model for bigrams, whereby all bigrams whose count is above three are considered and combined with tokenized unigrams of each tweet. For POS tagging CMU ARK Tweet NLP has been used. Furthermore, Spacy POS tagging removed location information as it contributes noise to a conversation. Additionally, the least 20 frequent words and words consisting of less than three characters were removed from the dataset before lemmatization was applied. Following this, duplicate tweets were removed using cosine similarity for those tweets having more than 90% similarity.

Feature representation that were investigated were BoW, TF-IDF, Word2Vec and Doc2Vec. The pre-trained Google word2vec model "GoogleNews-vectors-negative300.bin.gz" has been used for Word2Vec, for this POS tagging feature has not been considered as it is not supported by pre trained model. For Doc2Vec, each tweet is considered as a document and adds a Paragraph ID to each tweet with the tag of 'train' or 'test' for the respective data. The tagged data was then trained using the Genism Doc2Vec library (Rehurek et al., 2010) using both Distributed Bag of Words (DBOW) and Distributed Memory (DM) individually, in order to get 300 vector size document vectors from each model, which are then combined to get the document vector size of 600. Text categorization usually has high dimensionality. Thus, in order to reduce the dimensionality of data, Information Grain was used to limit features to the top 3,000 words features in the data.

RESULTS AND CONCLUSION

Our results are based on two types of data split; the first is leave one out (LOO), that is model tested on one dataset, and trains on the remaining 14 datasets. The second is cross-disaster training where a model is trained

on one type of disaster, and then tested on another type of disaster dataset. As the dataset has unbalanced classes, the F1 score has been used as the evaluation metric. The results presented in Table 1 indicate that word2vec outperforms all other types of representation in leave one out as well as cross-disaster training approach, while there is very minute difference between hybrid n-gram and unigram. This could be due to the use of a pre-trained model, which does not consist of words related to hashtags and bigrams. The result of cross-disaster training shows that disaster related tweets appear to be independent of the actual type of disaster. This could be due to similar vocabulary shared across the type of disaster in terms of donation, sympathy, needs, etc. The results strongly suggest that a pre-trained word2vec model gives better results than BoW, TF-IDF and Doc2Vec. This is due to the fact that a pre-trained model is trained on a comparatively large corpus, which creates a much improved context similarity representation. However, word2vec struggles with out of vocabulary words, which is more prevalent in text from a Twitter feed, as it contains human created hashtags and slang words.

Data trained on:	**Earthquake**		**Flood**		**Storm**		**LOO Avg F1**	
Feature	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
BoW Unigram	0.67	0.63	0.68	0.71	0.67	0.66	0.76	0.74
BoW Hybrid	0.66	0.64	0.70	0.69	0.71	0.66	0.77	0.73
BoW POS	0.67	0.63	0.69	0.71	0.75	0.67	0.76	0.74
Doc2Vec Unigram	0.71	0.61	0.68	0.66	0.65	0.66	0.79	0.71
Doc2Vec Hybrid	0.72	0.62	0.68	0.66	0.67	0.66	0.78	0.71
Doc2Vec POS	0.72	0.62	0.67	0.67	0.63	0.66	0.78	0.71
TF-IDF Unigram	0.72	0.58	0.73	0.69	0.63	0.65	0.79	0.75
TF-IDF Hybrid	0.69	0.54	0.72	0.62	0.62	0.60	0.79	0.74
TF-IDF POS	0.72	0.58	0.72	0.70	0.72	0.65	0.72	0.75
W2Vec Unigram	**0.78**	**0.70**	**0.75**	**0.73**	**0.81**	**0.71**	**0.81**	**0.76**
W2Vec Hybrid	0.76	0.68	**0.75**	**0.73**	**0.81**	0.70	0.80	**0.76**
W2Vec POS	NA	NA	NA	NA	NA	NA	NA	NA

Table 1: **Average F1 score for a = Informativeness Classification Result, and b = Information Type Classification**

REFERENCES

Ashktorab, Z., Brown, C., Nandi, M., & Culotta, A. (2014, May). Tweedr: Mining twitter to inform disaster response. In *ISCRAM.*

Imran, M., Castillo, C., Lucas, J., Meier, P., & Vieweg, S. (2014, April). AIDR: Artificial intelligence for disaster response. *In Proceedings of the 23rd International Conference on World Wide Web* (pp. 159-162). ACM.

Imran, M., Mitra, P., & Castillo, C. (2016). Twitter as a lifeline: Human-annotated twitter corpora for NLP of crisis-related messages. *arXiv preprint arXiv:1605.05894.*

Olteanu, A., Castillo, C., Diaz, F., & Vieweg, S. (2014). CrisisLex: A lexicon for collecting and filtering microblogged communications in crises. *In Eighth International AAAI Conference on Weblogs and Social Media.*

Rehurek, R., & Sojka, P. (2010). *Software framework for topic modelling with large corpora.* In Proceedings of the LREC 2010 Workshop on New Challenges for NLP Frameworks.

Schütze, H. (1995). Distributional part-of-speech tagging. *arXiv preprint cmp-lg/9503009.*

Win, Si Si Mar, and Than Nwe Aung. 2018. "Automated Text Annotation for Social Media Data during Natural Disasters." *Advances in Science, Technology and Engineering Systems Journal* 3(2): 119–27. https://astesj.com/v03/i02/p14/.

Yang, Y., & Pedersen, J. O. (1997, July). *A comparative study on feature selection in text categorization.* In Icml (Vol. 97, No. 412-420, p. 35).

Collaboration in Emergency Response Drills: an Experience with Firefighters

Paulo Victor R. de Carvalho
Instituto de Engenharia Nuclear, Brasil
paulov@ien.gov.br

Angela W. Righi
Universidade de Santa Maria, Brasil
angelawrighi@yahoo.com.br

Gilbert J. Huber
Universidade Federal do Rio de Janeiro, Brasil
gilbertjhuber@gmail.com

Jose Orlando Gomes
Universidade Federal do Rio de Janeiro, Brasil
joseorlando@nce.ufrj.b

INTRODUCTION

Emergency response drills, conducted mostly by means of simulations, are strategies used by various complex social-technical systems in order to prepare organizations and people to deal with foreseen or unforeseen risk situations. Collaborative work is part of these practitioners' work, which requires communication, cooperation, coordination, and awareness from them so they can properly do their job. Such collaborative work may be supported/aided by technological artifacts that ensure, for instance, a shorter response time, improved information sharing, and a better understanding of the local situation. Previous research in several types of firefighters' training (Huber et al., 2016) and observations of teams in Command and Control Centers (Carvalho et al., 2015) indicated the need of training approaches better suited to the reality of these practitioners, as well as better ways to analyze training results, enable an effective organizational learning. Immersed in this context, the purpose of this study was an analysis of an emergency response simulation exercise carried out by firefighters, to identify aspects of collaborative work to identify issues on the practitioners' communication, coordination, cooperation, and awareness.

METHODOLOGY

The research method is an empirical workplace study based on a systematic observation of training activities divided into several steps with different objectives which are highly interconnected. Even considered that is very difficult to list research activities in clear steps, due to the grounded nature of the research and its evolution over time, the main research phases were 1) Social construction, enabling the participation of the research team in the firefighters' activities; 2) Investigations of the standard operating procedures' (SOPs) norms, and work practices of firefighters; 3) Assist in the development and preparation of exercises; 4) Organization of the research team for observation and data collection; 5) Observation of the simulations including briefing, simulation, and debriefing phases; 6) Data analysis according to the 3C model (Fucks et al., 2005), discussion, and validation with firefighters' commanders.

RESULTS

Collaborative work issues appeared through communication, coordination, and cooperation as described in the 3C model of collaborative work (Fuks et al. 2005), and awareness (Dourish and Belloti,1992).

Communications: Communications between the participants and the command center relied solely on two-way radios. Radios are usually the tool used by the fire department in real work circumstances. In the simulation, each team was equipped with one radio, which was entrusted to a single member (the operator). That fact alone limited the access of all team members to the information exchanged with the command center and made it harder for them to understand all messages. Additionally, because all messages were heard by all groups, at different times during the simulation we noticed the groups had trouble understanding who was sending such messages or to whom they were being sent. The teams' ability to understand the content of the information was also compromised, and messages had to be repeated more than once so they could be understood by the main persons involved. Table 2 transcribes some excerpts from conversations showing these problems.

Coordination: The difficulty in assigning the roles of each team and plan future actions became even clearer when the Central Command radioed a new message of the exercise reporting on another event at the same site (vehicle fire). The Local Commander request a fire engine to the COCB, the Command center's deployment of the relevant team, and the team's doubt whether such vehicle was available engendered the messier part of the simulation, where everyone seemed to have trouble understanding what was going on, which response vehicles had been requested, and which ones were no longer at the site of the event. From then on, the teams were clearly unsure about what to do and tried to sort out which steps had been taken and which resources had been deployed. They had a hard time sharing the actual information and understanding the situation as a whole. That fact led the exercise facilitator to include an unplanned element, i.e. the media, to request information from the command post. Hence, information would have to be concentrated at that place, which encouraged the participants to share information and helped them understand the actual situation.

Cooperation: The actions to be carried out during the simulation had the common goal of handling the prescribed event: a collision between a train and car at a level crossing, with victims in different categories of risk. However, the fact the simulation did not actually feature victims at the site and lacked the physical number of response vehicles listed in the script, that is, the teams had one physical vehicle that stood in for up to four, seems to have compromised the exercise, especially regarding the aspect of cooperation. The teams kept being dispatched to the site, but as they got there they did not have common goals to be achieved. They focused on assessing the scene, deciding on whether they needed backup and on the "virtual" transport of victims, and filling out the forms supplied for the exercise.

Awareness: Understanding the messages sent, resources available, actions already carried out, and backup needed at the site and by fellow officers are examples of awareness-related aspects that permeate and provide support for coordination, cooperation, and communication. Different resources were included in the exercise to provide information and let individuals and teams to get a picture of the event: (i) two-way radios, the main resource for communications between the field and the command center; (ii) the flip chart, where the exercise's main messages were posted, and which was at the site; (iii) the command post, tasked with centralizing the information and allowing everyone to see the (iv) organization chart listing the information on the then-current level of the event and the persons in charge of each macro activity; and (v) as a resource included for the exercise, the very form which the teams were required to fill out with the information exchanged in the course of the simulation. However, despite the resources for accessing and sharing information, at several points during the exercise it was observed participants were unsure at which level the simulation was, who was at the site, what they were supposed to do, how the team was expected to behave, or who to turn to for information.

CONCLUSIONS AND FURTHER WORK

Scarcity and information overload have great impact on building understanding of the situation among team members and control and command, and consequently on decision making during crisis events. Under such constraints collaborative work supported by adequate tools is paramount for a better response. Workplace studies based on ethnographic methods have proved to be a good approach for analyzing the scenarios as explored in this study. It was possible to observe confusion in the transferring of information, extensive need to information repetition, and the high dependence of the command center on the flow of information coming in from the teams. The officers lacked the clarity of the information and thus spent more time soliciting radio confirmations and trying to understand what was actually happening, and in some cases misunderstanding what was communicated. The analysis of communication shown that radio communication was not enough, therefore future work on new a framework for the development of communications tolls is important.

REFERENCES

Carvalho, P.V.R., et al. (2015) Exploring issues on resilience and brittleness in a Command and Control Center during FIFA`s 2014 World Cup in Rio de Janeiro. Proceedings of the 12th International Conference on Information Systems for Crisis Response and Management, Kristiansand, 2015.

Dourish, P. and Belloti, V. (1992) Awareness and Coordination in Shared Spaces, Proceedings of CSCW '92, ACM Press, Toronto.

Fuks, H., Raposo, A., Gerosa, M. A. and Lucena, C. J. P. (2005) Applying the 3C Model to Groupware Development, International Journal of Cooperative Information Systems, 14,2-3, 299-328.

Huber G., et al.(2016) Firefighting emergency response exercise? An analysis of standardization and resilience. Proceedings of the 13th International Conference on Information Systems for Crisis Response and Management. Rio de Janeiro, 2016.

Evaluating the Performance of Deep Learning Methods for Hurricane-Related Image Classification

Matthew Johnson
The University of Texas at Austin
mjohnson082396@gmail.com

Dhiraj Murthy
The University of Texas at Austin
Dhiraj.murthy@austin.utexas.edu

Brett W. Robertson
The University of Texas at Austin
Brett.robertson@utexas.edu

William Roth Smith
The University of Texas at Austin
rothsmith@utexas.edu

Keri K. Stephens
The University of Texas at Austin
keristephens@austin.utexas.edu

INTRODUCTION

Global social media use during natural disasters has been well documented (Murthy et al., 2017). In the U.S., public social media platforms are often a primary venue for those affected by disasters. Some disaster victims believe first responders will see their public posts and that the 9-1-1 telephone system becomes overloaded during crises. Moreover, some feel that the accuracy and utility of information on social media is likely higher than traditional media sources. However, sifting through content during a disaster is often difficult due to the high volume of 'non-relevant' content. In addition, text is studied more than images posted on Twitter, leaving a potential gap in understanding disaster experiences. Images posted on social media during disasters have a high level of complexity (Murthy et al., 2016). Our study responds to O'Neal et al.'s (2017) call-to-action that social media images posted during disasters should be studied using machine learning.

METHODOLOGY

Our study develops/evaluates a transfer learning framework for classifying 17,843 images posted to Twitter. We use VGG-16, a Convolutional Neural Network (CNN) to categorize images shared on Twitter during Hurricane Harvey in 2017 by their urgency, relevance, time period, and the presence of damage and relief motifs.

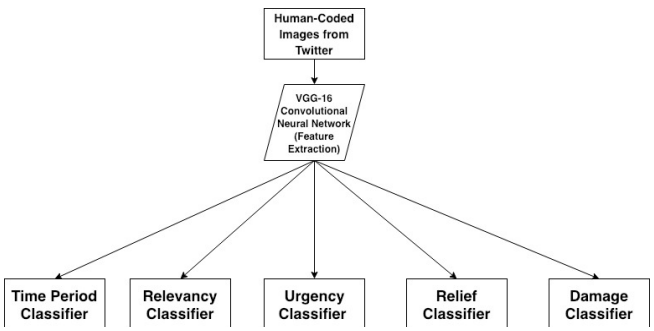


Figure 1: Deep Learning Framework

Human Annotation: To develop the 'training' dataset (i.e., data used to train an algorithm) for our study, we

randomly sampled 1,128 images (approximately 6.45% of all images collected) and human-coded these images using a rubric with categories drawn from established crisis literature.

Deep 'Transfer' Learning for Feature Extraction: Because most deep learning techniques require large datasets and computational resources, it is common to employ a pre-trained model and adapt it to a specific learning task. In this study, we treat output from the second-to-last layer of VGG-16 as low-dimensional 'feature vectors' representing each image. Using these feature vectors, we trained five multilayer perceptrons to classify images by time period, relevancy, urgency and the presence of 'damage' and 'relief' themes. We used nearly identical model architectures for the classifiers, and we evaluate each classifier's accuracy, categorical cross-entropy loss, and F1(-macro/-micro) scores.

RESULTS

Existing crisis-related image filtering approaches using deep learning indicate state of the art baselines with F1 scores ranging from 0.60-0.70 (Nguyen et al., 2017). Our results, particularly with the relevancy, urgency, and damage classifiers (see Table 1), provide evidence that we can obtain high-performance, robust classifiers even with just 1,128 human-annotated images.

Classifier	Time Period	Urgency	Relevancy	Damage	Relief
Training Loss	0.6398	0.9514	0.3313	0.1441	0.128
Training Accuracy	0.7705	0.6098	0.9035	0.9957	0.9484
Validation Loss	0.7515	1.0841	0.5222	0.253	0.2335
Validation Accuracy	0.677	0.6195	0.8186	0.9023	0.9336
F1 Macro Score	0.3735	0.5847	0.752	0.6973	0.824
F1 Micro	0.5012	0.6157	0.811	0.4375	0.7568

Table 1: Classifier Results for Accuracy, Loss, and F1

CONCLUSIONS AND FURTHER WORK

Our framework reliably classifies images based on relevancy, urgency, and damage. Stakeholders such as emergency response organizations do not have to create custom models. Our transfer learning models can be used real-time to filter images by urgency, relevancy, and damage. During future hurricane events, this will not only save time, but help target limited resources to look at relevant images posted on social media

ACKNOWLEDGMENTS

This work was supported by a grant from the National Science Foundation [award # 1760453].

REFERENCES

Murthy, D., & Gross, A. J. (2017). Social media processes in disasters: Implications of emergent technology use. *Social Science Research*, *63*, 356-370.

Murthy, D., Gross, A. J., & McGarry, M. (2016). Visual social media and big data: Interpreting Instagram images posted on Twitter. *Digital Culture & Society*, *2*(2), 113-134.

Nguyen, D. T., Alam, F., Ofli, F., & Imran, M. (2017). Automatic image filtering on social networks using deep learning and perceptual hashing during crises. In *Proceedings of the International Conference on Information Systems for Crisis Response and Management (ISCRAM)*. Albi, France.

O'Neal, A., Rodgers, B., Segler, J., Murthy, D., Lakuduva, N., Johnson, M., & Stephens, K. K. (2018). Training an emergency-response image classifier on signal data. In M. Kantardzic & M. Sayed-Mouchaweh (Eds.), *Proceedings of the 17th IEEE International Conference on Machine Learning and Applications (ICMLA)*: Orlando, FL. doi:10.1109/ICMLA.2018.00119

Multi-agent planning and execution with risk analysis and multi-criteria optimization: the case of rescue plans to environmental and humanitarian crisis

Cendrella CHAHINE
ULF Tripoli/ LGP-ENIT
cendrella.chahine@enit.fr

Thierry VIDAL
LGP-ENIT
thierry.vidal@enit.fr

François PERES
LGP-ENIT
francois.peres@enit.fr

Mohamad El FALOU
ULF Tripoli
mohamad.elfalou@gmail.com

INTRODUCTION

A disaster seriously disrupts the functioning of a society and generates human, material and economic losses. Unfortunately, some are weakly predictable such as the terrorist. But even the predictable ones, like the cyclones whose intensity remains difficult to assess are not always easy to forecast in terms of damage. Over the past 10 years, disasters have killed more than 700,000 people worldwide, 1.4 million injured and total economic losses of more than 1,100 billion euros. For example, on Friday, the 23rd of August 2013, Tripoli, north of Lebanon, was hit by terrorists. Two Sunni mosques were struck by two car bombs, leaving at least 42 dead and 500 others injured. Likewise, on January 12, 2010, an earthquake measuring 7.3 on the Richter scale (between 0 and 12) rocked Haiti for 35 seconds. More than 220,000 people were killed, more than 330,000 were wounded and about 1.3 million were homeless. Due to the sudden occurrence of disasters, the reaction must be quick and efficient as much as possible in order to minimize the human loss by providing help and rescue to the injured people. The main objective is to assist and take them as fast as possible to the nearest treatment center that can treat their cases. The presented work concerns the definition of a new decentralized model combining proactive-reactive approaches and Multi-agent systems (M.A.S) for solving the planning problem of a terrorist attack scenario. It is dedicated to present a PhD research work involving both The Production Engineering Laboratory in France and the research laboratory of the Lebanese-French University of Tripoli in Lebanon.

METHODOLOGY

Bidot et al. [1] presented four different approaches for planning under uncertainty distinguishing: reactive, proactive, progressive or continuous, and mixed techniques, and associated with both design and execution phases. The first one aims at creating a plan, while the second one is to its deployment on the real situation. The question is how and when it can be created or modified according to the technique used. To value uncertainties two theories mainly apply respectively related to: fuzzy logic or probability theory. The fuzzy logic approach works with variables or imprecise events while the probability theory uses precise but random events. In our case, planning and execution are shared among distinct professionals in charge of deciding or performing the tasks. Multi-Agent Systems (MAS) [2] are a natural approach to cope with that, and may also appear more effective to deal with uncertainty tan centralized systems. One of the most famous definitions of agent, set by Russell [3], is to consider an agent like an entity perceiving its environment through sensors and acting on this environment via autonomous triggers. Thus, MAS is an organized corpus of agents in which a certain number of phenomena comes out as the result of interaction between these aforesaid agents.

RESULTS

We present a scenario of terrorist attack discussed in centralized and decentralized models. We then analyzed both models by adding few assumptions to the scenario, unknown number of victims, blocked or impassable road to access the crisis site or the nearest hospital. The main concern of our problem is to intervene as quickly as possible to evacuate the greatest number of wounded and to transfer them to the nearest and the most appropriate health centers.

With this in mind, the proactive-reactive approach is used. We suppose that each resource is an agent:

- **First case**: EMAS (Emergency Medical Assistance Services), two MERS (Mobile Emergency and Resuscitation Services) and two hospitals.
- **Second case**: EMAS, two MERS, two hospitals and a Transport system.

We assume that the number of resources is enough, there is no communication problem and the capacity of the hospitals is sufficient for the number of victims. Also, we suppose that every new condition or parameter that will be added in the next steps is not predictive, so the reactive technique will be used. We should note that the solution developed in the first case model when the number of victims is unknown, can be applicable in the second case model too.

Unlike the centralized model when only one agent has the responsibility of making a decision, a decentralized model gives each agent a degree of autonomy. So in some cases, he can decide what to do. For example, in centralized models, $MERS_1$ and $MERS_2$ should always communicate with the EMAS. They ask the EMAS, which hospital to send the wounded, which wounded should be served first and which hospital to send each injured person. When the road is blocked, they wait until the EMAS find a solution after the transport agent proposes the possible roads to EMAS. While in the decentralized models, $MERS_1$ and $MERS_2$ can communicate with each other directly and take some decisions without the intervention of EMAS. The transport agent chooses the best road and send it to $MERS_1$ and $MERS_2$. Thus, we notice that the communication between the agents is high in the centralized models.

Moreover, we should mention that the transport agent in the decentralized model, will give the MERS the best and the shortest road in real-time so it will never be blocked. A more interesting problem that we propose to analyze is when the situation is not completely observable by the transport agent and the MERS will only discover a blocked road when it reaches it.

CONCLUSIONS AND FURTHER WORK

We have presented a proactive-reactive approach to multiple centralized and decentralized models for terrorist attack crisis aiming at minimizing human losses. We compared the models and highlighted their difference. In addition, we presented the different techniques to generate a plan. Then, we aim to construct a distributed decision support model for the construction and execution of coordinated multi-agent intervention plans. The next issues to be addressed are related to dynamic environment planning and tasks distribution between agents. If possible more autonomy will be given to the agents to be able to make decisions. Furthermore, we will make a formal analysis of cost and quality. Thus, we will focus on minimizing the cost and increasing the quality. We will study the classic planning techniques in multi-agent systems based on the generalization of the Markov decision process. Then, we will compare them and choose an algorithm that will allow us to represent our scenario. We will simulate and test all the models and propose others to indicate which one will be the best to solve addressed issues. For example, we will test the models by comparing a makespan to save the wounded. Thus, we will optimize the transport operation by minimizing the transport's duration between the crisis zone and the treatment center.

Finally, and after having designed the multi-agent system, the next step will be to select the platform for the implementation of the model. We will choose the JADE platform because of its simplicity and its aptitude to make prototypes using native JAVA programming language.

REFERENCES

[1] Bidot, J., Vidal, T., Laborie, P., & Beck, J. C. (2009). A theoretic and practical framework for scheduling in a stochastic environment. *Journal of Scheduling*, 12(3), 315–344.

[2] Malas, A., EL Falou, S., EL Falou, M., & Cardon, A. (2016). Solving On-Demand Transport Problem through Negotiation.

[3] Russell,S. and Norvig P. (2003) Artificial Intelligence: A Modern Approach, Prentice Hall.

CroMa – Crowd Management in Transportation Infrastructures

Alexander Gabriel
University of Wuppertal
gabriel@uni-wuppertal.de

Andreas Lotter
University of Wuppertal
lotter@uni-wuppertal.de

Frank Fiedrich
University of Wuppertal
fiedrich@uni-wuppertal.de

INTRODUCTION

The high and continuously rising number of passengers using public transportation in Germany is leading to an expansion of the services offered by public transport operators. The existing transportation infrastructures, especially the railway stations, can only partly cope with this rapid growth in passenger volume. Overcrowding on platforms and access routes is already occurring, especially in the event of operational disruptions by natural disasters or major public events. This crowding may lead to passenger injuries or to a standstill of operations for safety reasons. The collaborative research project "Crowd-Management in Transportation Infrastructures – CroMa" aims at improving the robustness, safety and performance of railway stations during peak loads. For this purpose, improved building regulations, suitable crowd management as well as guidelines for risk management, resilience and inter-organizational information management will be developed.

Within CroMa, the Institute of Public Safety and Emergency Management conducts research on the identification and modelling of information flows between the various stakeholders. An analysis of existing information management concepts and domain specific crisis scenarios will help to develop an information flow process model and guidelines for effective inter-organizational information management.

The poster "CroMa - Crowd Management in Transportation Infrastructures" describes the collaborative research project of the same name. The poster contribution highlights the research questions addressed within the framework of the project as well as the underlying methodological approach. The expected results, including guidelines for end users, are also presented.

METHODOLOGY

Within this project, the Institute for Public Safety and Emergency Management is focusing on the design of a holistic crisis and risk management system across organizational and system boundaries. This includes the development of inter-organizational crisis management guidelines for operators of interconnected transportation infrastructures. In addition, the research project will concentrate on maintaining the performance of transportation infrastructures – especially railway stations – even under difficult and critical operating conditions.

During the initial phase of CroMa, information flows will be recorded and translated into a generic UML model. A user-oriented approach is used to identify these information flows. Field and practical observations (e.g. crisis management teams and incident command teams at major events) will be performed to investigate information flows and decision-making processes in real environments. These are then analyzed and used to develop the model. In this way, they represent the as-is situation.

Besides analyzing existing concepts for cross-organizational information exchange and decision making, the project CroMa develops application scenarios with a special emphasis on information management. Past incidents related to rail transportation have been collected and will be analyzed and clustered according to different characteristics (e.g. predictability, duration, impact). The results of this analysis are reflected, validated and refined in guided expert interviews. Linking the analysis of past events and expert interviews, conclusions will be drawn on the subsequent development of a causal model for possible future scenarios. A suitable approach for the development of this causal model is provided by the functional resonance analysis method.

Based on the model of the as-is state and the past and possible future scenarios, a desired state of the communication model and a set of recommendations and guidelines for effective inter-organizational cooperation will be developed. These guidelines will be validated within the framework of an expert panel or workshop. Subsequently, a publication and broad communication of the guidelines is planned.

The involvement of end users includes the participation in qualitative expert interviews, field studies in Germany, Austria and Switzerland as well as the coherent scenario and guideline development. In addition to an impact assessment for various scenarios on the transportation system's performance, a major focus will be on the development of an information flow process model. This model will serve as a basis for the above mentioned end-user guidelines.

RESULTS

Expected results of the research project are the UML process model with the identified interfaces and information flows as well as the scenarios and the impact assessment on the performance of the transport system. They provide the basis for new concepts for effective cross-organizational cooperation between the participating organizations and the development of a uniform terminology. The guidelines for the inter-organizational exchange of information to be developed within the framework of the project are intended as a future basis for the creation or optimization of information management systems.

CONCLUSION AND FURTHER WORK

In the course of the carnival events in the Rhineland, Germany, it was already possible to observe incident command teams deployed in a real situation. Additionally at this occasion, initial orienting field observations were conducted. A number of preliminary interviews with experts has been carried out. These are currently undergoing evaluation.

The analysis of past events and the development of a causal model are subject of the current research in the project. First results of the work already carried out are expected in autumn 2019.

ACKNOWLEDGMENTS

The collaborative research project CroMa is funded by the German Federal Ministry of Education and Research.

Towards Bridging the Gap between Demand and Supply in Humanitarian Geodata Use

Melanie Eckle
GIScience Research Group, Institute of Geography, Heidelberg University
Eckle@stud.uni-heidelberg.de

Sven Lautenbach
GIScience Research Group, Institute of Geography, Heidelberg University
sven.lautenbach@uni-heidelberg.de

Alexander Zipf
GIScience Research Group, Institute of Geography, Heidelberg University
zipf@uni-heidelberg.de

INTRODUCTION

In humanitarian practice, high-quality and context-specific geodata is crucial to come to informed decisions and to efficiently coordinate and conduct humanitarian activities. While humanitarian actors also make use of internal resources to collect various kinds of geodata, they mostly rely on external geodata providers. This is mainly due to a lack of own resources, appropriate expertise, and the complexity of humanitarian contexts. However, both research and practice show an imbalance between the geodata provided and humanitarian actors' needs and requirements (cf. Gralla et al. 2015; Van den Homberg et al. 2018), which leads to less efficient use of geodata in humanitarian activities.
The main aim of the work is to close this gap through a methodological approach that enables structured communication of these needs and requirements of humanitarian actors - to enable better understanding and in consequence, to facilitate geodata creation and sharing with a better fit for humanitarian purposes.

METHODOLOGY

The communication and identification of humanitarian geodata needs are addressed through a multi-tiered approach that was developed in the scope of the first research phase. This methodological approach begins with a comprehensive literature review and includes theoretical and practical activities as well as empirical analyses. As part of the literature review, on the one hand, conceptual spaces and perception, as well as insight and survey methods were elicited to acquire a thorough understanding of the current state of the art around knowledge extraction, which can consequently be put to use to gain an understanding of humanitarian actors' mindsets and perceptions. On the other hand, the literature review also focused on geodata quality as well as geodata use in humanitarian contexts. This part was extended with a review of reports from own projects of the authors with humanitarian actors, which further illustrate current geodata usage and related humanitarian practice.
Based on these efforts, an introductory survey was developed through which participants can provide insights about their background, previous experiences, and lessons learned as well as perceived limitations related to geodata usage in their current tasks. Building on this introductory survey, two additional approaches were developed to get a deeper understanding of the participants' needs and requirements as well as current hindrances in geodata use: the first approach is based on the concept of the Analytic Hierarchy Process (AHP) (cf. Saaty 1980, 2013), the second one is based on Design Thinking (cf. Plattner 2013).
The AHP is a Multi-Criteria Decision Making (MCDM) method that was included in the methodology to enable prioritization of geodata characteristics by humanitarian geodata users. In this survey-structured approach, participants are asked to conduct pairwise comparisons of geodata characteristics, based on their insights provided in the introductory survey, to learn about their main needs and requirements around humanitarian geodata use. Likewise to the AHP, the Design Thinking tools enable information gathering, but furthermore allow sympathizing and empathizing with participants. These tools are utilized to receive deeper insights about the humanitarian geodata users' perception and to assess, why they address their tasks the way they do. For this

second approach, small groups of participants join Remote Design Thinking Workshops, in which they discuss their previously provided insights, again building on results from the introductory survey.
As both methods can be applied in remote scenarios, they consequently allow for involving humanitarian actors in their oftentimes remote work locations. However, both approaches are yet to be assessed regarding their suitability for the communication and consequently the identification of the main needs and requirements of humanitarian geodata users.

RESULTS

Humanitarian actors and representatives of national and international humanitarian organizations, as well as scientific institutes, already supported the presented work through their active contribution in the introductory surveys, Remote Design Thinking Workshops, and AHPs. They hereby provided insights about their current approaches and challenges all around humanitarian geodata use. The AHP provided insights about more and less important geodata characteristics and related reasoning, the Remote Design Thinking Workshop furthermore allowed participants to discuss their perspectives, and to develop ideas towards related improvements.
Initial results indicate that, on the hand, accessibility, availability, and accuracy of geodata seem to be of greater importance compared to usability, completeness and the geodata being up-to-date. On the other hand, participants also reported about the current limitations in geodata use. These include lack of standardization and metadata, which both seem to pose a major challenge for efficient geodata use. Additionally, limited geodata sharing, which is partially also related to these previous factors, was discussed to hinder geodata use and to moreover affect geodata availability and accessibility. Trustworthiness was furthermore mentioned as being of great importance and at the same time, lack of trustworthiness as being a great hindrance in current geodata use.

CONCLUSIONS AND FURTHER WORK

The main aim of the presented research is to enable structured communication of the needs and requirements of humanitarian actors to close the gap between demand and supply in humanitarian geodata use. First results of the methodology already showed the potential for the communication of needs and requirements as well as current limitations and thus for knowledge gathering around humanitarian geodata use.

Further workshops, as well as AHPs, are already planned to get a more comprehensive sample and to evaluate findings gathered from the initial participants. Results will furthermore be assessed to evaluate the suitability of the two approaches in comparison to each other.

ACKNOWLEDGMENTS

The content of the poster was developed by Melanie Eckle as part of her Master Thesis. The topic draws on related work of the Heidelberg Institute for Geoinformation Technology/ GIScience Research Group at Heidelberg University which is core funded by the Klaus Tschira Foundation.
The research idea was developed in collaborative projects within the Missing Maps project and in collaboration with the named co-authors as well as Dr. Franz-Benjamin Mocnik.
We want to thank all participants of the research study for their valuable contributions.

REFERENCES

Gralla, E., Goentzel, J., Van de Walle, B. (2015): Understanding the information needs of field-based decision-makers in humanitarian response to sudden onset disasters. In: Proceedings of the 12th International Conference on Information Systems for Crisis Response and Management, pp. 1–7.

Plattner, H. (2013): An introduction to Design Thinking', Institute of Design at Stanford. doi: 10.1007/978-1-4302-6182-7_1.

Saaty, T. L. (2013): The Modern Science of Multicriteria Decision Making and Its Practical Applications: The AHP/ANP Approach', *Operations Research*, 61(5), pp. 1101–1118. doi: 10.1287/opre.2013.1197.

Saaty, T. L. (1980): The analytic hierarchy process. New York, N.Y. [et al.]: McGRawHill.

Van den Homberg, M., Monné, R., Spruit, M. (2018): Bridging the Information Gap: Mapping Data Sets on Information Needs in the Preparedness and Response Phase. 10.1007/978-3-319-91068-0_18.

Geographic and Content-Based Prioritization of Tweets for Emergency Response: The Case of Weather-Related Disaster Events

A. Marcela Suarez
University of California, Santa Barbara
amsuarez@ucsb.edu

Keith C. Clarke
University of California, Santa Barbara
kcclarke@ucsb.edu

INTRODUCTION

Content shared on Twitter usually represents timely, updated, and sometimes on-site reports. Because of this, and the speed and ease with which information is shared through this micro-blogging platform, forecasters and emergency managers have tried to leverage tweets as an on-the-ground reference for both confirming the occurrence of weather-related disaster events and for tracking their local impacts and damage. However, since Twitter data is massive, semantically varied, noisy and spatio-temporally uncertain (Steiger et al. 2015), little of this information is made useful and when it is, it usually requires exhaustive manual filtering - searching individually for tweets related to a specific event. This raises the questions of how can we both identify and prioritize tweets on weather-related disaster events based on their reliability in a timeframe that is useful for emergency response, and ultimately, which factors define their reliability.

This study presents an approach for prioritizing tweets so that they can be used by emergency managers and decision makers to assess local effects and damage caused by weather-related disaster events. Using Hurricane Harvey as a case study, we demonstrate how authoritative data, such as on-the-ground reports provided by weather spotters trained by National Weather Service (NWS), as well as the National Flood Hazard[1] information and damage maps created by the Federal Emergency Management Agency (FEMA) can be used to prioritize tweets based on their geographical location, and so allow them to assist in weather impact assessments.

DATA

This research relies on two type of datasets: a dataset of tweets, and datasets containing authoritative information. The Twitter dataset consists of 4,486 geotagged tweets sent within the US State of Texas selected from a sample of 7,041,866 tweets that were randomly collected from August 18 to September 22, 2017. The data was collected by the University of North Texas (UNT) and the original dataset is publicly available in the digital repository hosted by the UNT libraries[2].

Authoritative datasets consist of information of three different types: a flood hazard assessment, citizen reports sent during the emergency and a damage assessment carried out after the disaster. The first two were used as a reference to prioritize the tweets, and the last one was used for validating the prioritization. Authoritative citizen reports were contributed by Weather Spotters who are volunteers trained by the NWS as part of a program called SKYWARN. Spotters' reports were extracted from NOAA's historic Storm Event Database[3]. Geographic information related to hazards and the damage and impact caused by Harvey is provided by FEMA.

METHODOLOGY AND RESULTS

1 https://www.fema.gov/national-flood-hazard-layer-nfhl
2 https://digital.library.unt.edu/ark:/67531/metadc993940/
3 ftp://ftp.ncdc.noaa.gov/pub/data/swdi/stormevents/csvfiles

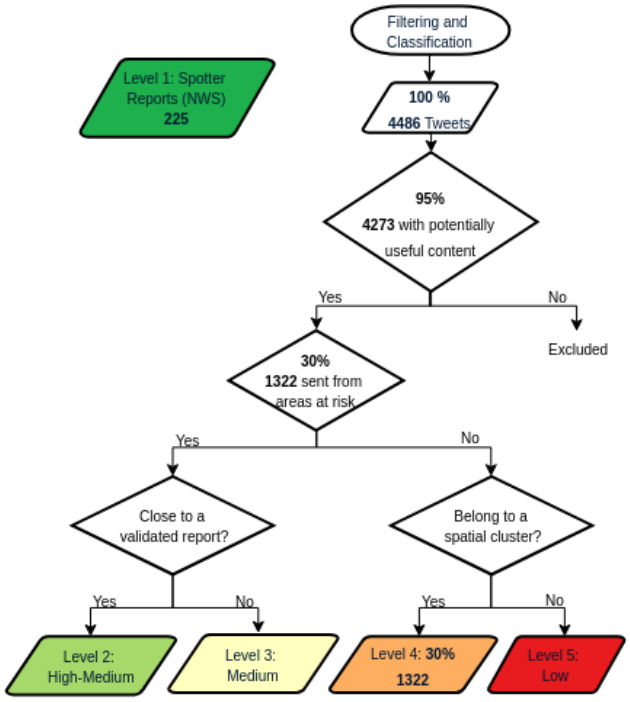


Figure 1. Flow Chart explaining process to filter and classify tweets

Five stages characterize this study: Data preparation, content analysis, spatial clustering, proximity analysis, and filtering and classification.

Data Preparation. During this stage the Twitter dataset was filtered in order to be used to address the objectives of this study and it was also preprocessed in order to reduce noise and any redundancy among the tweets.

Content Analysis. We used topic modeling to discover topics of tweets and filtered out those with no informative for the emergency response, such as those expressing sympathy and emotional support.

Spatial Analysis. We estimated if a tweet was sent from a flooded area by intersecting the two map layers that represent each dataset.

Spatial Clustering Analysis. It was used to identify areas with high densities of tweets. We used the hierarchical DBSCAN algorithm to identify and label spatial clusters.

Proximity Analysis. It allowed us to evaluate if around the area where a tweet was sent there was also a validated report. A hexagonal grid was used to represent "spatial vicinity." Each tweet and spotter report was assigned to a unique hexagon or unit area. Using this grid we evaluated whether any spotter report was sent from a hexagon that also contains tweets.

Filtering and classification. Figure 1 illustrates this stage which consists of the prioritization process and uses the results from the previous stages. The percentage of tweets retained in each stage is also included in this figure.

CONCLUSIONS AND FURTHER WORK

This research provides a framework that leverages geographic information to assess tweets reliability. Geographic information related to hazards as well as citizen reports validated by the NWS serve as an excellent reference to assess tweets reliability.

Although only a small portion of tweets actually provide useful information for emergency responders, they are still a good data source to complement official information.

Next steps include: i) Estimation of the optimal hexagon size in the proximity analysis. Grids of hexagons at a range of sizes will be evaluated by comparing the overall coefficient of variation–the hexagon size with the highest coefficient of variation will be considered optimal. ii) FEMA Modeled Building Damage Assessment data will be used to validate results from the filtering process.

ACKNOWLEDGMENTS

Travel to present this research at the ISCRAM 2019 conference was funded by the Jack and Laura Dangermond Geography Travel Fund and the UCSB Doctoral Student Travel Program.

REFERENCES

Steiger, E., de Albuquerque, J. P., & Zipf, A. (2015). An advanced systematic literature review on spatiotemporal analyses of twitter data. *Transactions in GIS (3)*.

Serious gaming for training non-technical skills in crisis management and emergency response

Isabelle Turcotte
Laval University
isabelle.turcotte.2@ulaval.ca

Gabrielle Teyssier-Roberge
Laval University
gabrielle.teyssier-roberge.1@ulaval.ca

Rego Granlund
RISE Research Institutes of Sweden
rego.granlund@ri.se

Sébastien Tremblay
Laval University
Sebastien.Tremblay@psy.ulaval.ca

INTRODUCTION

A series of R&D initiatives – recently completed and on-going projects – carried out within an interdisciplinary (cognitive sciences, ergonomics, software engineering) and international (Canada and Sweden) partnership that is comprised of universities (U Laval, Linkoping U) and college (Campus Notre-Dame-De-Foy, Canada) researchers, developers and engineers from the industry (OVA, Thales) and subject-matter experts from emergency response teams (Quebec security department) is presented. Some of the work is still in progress and part of PhD research work. The main researcher – Prof S. Tremblay is based at Laval University, Quebec City, Canada.

The aim of our R&D program is to develop and validate innovative adaptive systems and tools for the training of non-technical (cognitive) skills in crisis management and emergency response. Crisis situations are generally characterized by severe threats, uncertainty, and time pressure, which all pose challenges for first responders under demanding circumstances. We present two on-going projects related to the training of interoperability in joint operations as well as other key cognitive skills: A first project is focused on the use of serious gaming and the other project with the use of VR within collaborative environments. In both cases the scenarios are designed to require teamwork, coordination of decisions and actions, communication and collaborative sensemaking and also provide a set of behavioral indicators and biometrics in order to monitor skill acquisition and the cognitive-affective state of the trainees.

METHODOLOGY

Serious Gaming. Serious games are widely recognized for their potential to foster learning and the acquisition of non-technical skills. We used C3Fire – a gamified microworld that can be used by either an individual or a group of people collaborating with the goal to extinguish a forest fire (Granlund 2002) in order to train interoperability. It is a very flexible and tractable platform that allows researchers to simulate characteristics of real-world crisis management environments (complex, dynamic, and opaque). The collaboration can be supported by different means of communication and it is possible to configure the simulation so that inter-dependencies are created between the different members. Twenty-four teams of four participants completed four scenarios, each lasting 10 minutes. A set of cognitive and teamwork metrics was developed to assess team effectiveness. These included measures of performance, coordination effectiveness, monitoring effectiveness, adaptability, pattern of communications, and shared mental models.

VR training. By invoking a combination of realistic unforeseen events, taskload variations and time pressure, virtual reality (VR) can serve to train responders to perform under the acute stress and complexity of real-life crisis situations, and facilitate learning of non-technical (cognitive) skills. The first objective of this project was to develop a realistic simulation that placed four supervisors from different services (e.g., police, fire, paramedic, civil security) in a crisis situation in which they must communicate and coordinate for an efficient emergency response. This was done, in concert with subject matter experts, by defining the learning objectives and the team

and individual behaviors that could indicate the acquisition of non-technical skills. The second objective was to develop and integrate the automatic calculation of behavioral metrics within the VR platform allowing the assessment of interoperability and learning rate. Ten teams of four real life responders tested the simulation in which a criminal act resulted in an ammonia leak threatening citizens in an arena.

RESULTS

Results from the C3Fire project revealed that team members achieved better coordination as they progressed through the scenarios. This learning effect suggests that it could be beneficial to train team members to coordinate their actions efficiently. Preliminary results from the VR training project showed that the perceived amount of workload reflected the taskload associated with each service. The testing of metrics of interoperability and of non-technical skills provided valuable lessons learned regarding technical challenges.

CONCLUSIONS AND FURTHER WORK

Both serious gaming and VR provide a cost-effective means to train non-technical skills using simulated scenarios that are realistic in terms of time course, nature of critical events, and ensuing emotional states. These training methods could complement traditional training means by optimizing trainee potential while reducing logistical inconvenience, monetary costs and potential risks of field training exercises.

REFERENCES

Teyssier-Roberge, G. & Tremblay, S. (2018) Adaptive serious gaming for the development and assessment of 21st century skills. *1st International Conference on Human System Engineering and Design*. Reims, Champagne-Ardem, France.

Turcotte, I., Rivard, L., Breault, K., Dumur, H., Verville, J.-P. & Tremblay, S. (2018) Validation of a virtual reality training simulation for interoperability in crisis management emergency responders. *9th AHFE Conference*. Orlando, U.S.

Parent, M., Gagnon, J.-F., Falk, T. H. & Tremblay, S. (2016) Modeling the operator functional state for emergency response management. *Proceedings of the 13th International Conference on Information Systems,* Rio de Janeiro, Brazil.

Baroutsi, N., Berggren, P., Johansson, B. J., Nählinder, S., Granlund, R., Turcotte, I. & Tremblay, S. (2014) Assessing development of team training in emergency management. *11th International ISCRAM Conference.* Lisbon, Portugal.

Berggren, P., Baroutsi, Berggren, P., Johansson, B. J., Baroutsi, N., Turcotte, I. & Tremblay, S. (2014) Assessing team focused behaviors in emergency response teams using the shared priorities measure. *Proceedings of the 11th International Conference on Information Systems,* Lisbon, Portugal.

Lebel, B., Gagnon, J.-F., Banbury, S., Rivest, M., Couderc, F., Comtois, J.-P. & Tremblay, S. (2013) SYnRGY: A realistic emergency management simulation platform for training. *10th International ISCRAM Conference.* Baden-Baden, Germany.

Gagnon, J.-F., Couderc, F., Rivest, M., Banbury, S. & Tremblay, S. (2013) Using SYnRGY to support design and validation studies of emergency management solutions. *Proceedings of the 10th International Conference on Information Systems,* Baden-Baden, Germany.

Turcotte, I., Tremblay, S., Farrell, P. & Jobidon, M-E. (2013) Using a functional simulation of crisis management to test the C2 Agility Model parameters on key performance variables. *Proceedings of the 18th* ICCRTS. Virginia, U.S.

Gagnon, J.-F., Couderc, F., Rivest, M. & Tremblay, S. (2012) Capturing the task model of experts in emergency response using SYnRGY. *Proceedings of the 9th International Conference on Information Systems,* Vancouver, Canada.

Tremblay, S., Granlund, R., Berggren, P., Jobidon, M.-E., Holmberg, M. & Turner, P. (2012) A multiteam international simulation of joint operations in crisis response. *Proceedings of the 9th International Conference on Information Systems,* Vancouver, Canada.

Granlund, R. & Granlund, H. (2011) Using simulations to study the impact of GPS information in crisis response organizations. *8th International Conference on Information Systems,* Lisbon, Portugal.

A comparison of two methodologies to assess shallow landslide risk

Erica Akemi Goto
University of California, Santa Barbara
ericagoto@gmail.com

Keith Clarke
University of California, Santa Barbara
kcclarke@ucsb.edu

INTRODUCTION

Landslides are natural processes that can be hazardous events when they threaten human lives and assets (Keller, 2011), and their incidence can be increased by improper land use, such as irregular urbanization and the construction of dams and roads without good engineering planning. Landslide disasters and catastrophes are not new, and the loss of human life to them is common in developing countries. Many people live in risk prone-areas in the Southeastern part of Brazil (IBGE, 2018). Major cities such as Sao Paulo and Belo Horizonte have 6% and 16% of their population living in at-risk areas, respectively (IBGE, 2018). Moreover, mapping these risk areas are critical for managing and mitigating the risk. Municipalities can use the mappings to monitor the risk areas and to allocate resources or prioritize to relocate residents living in high and very high risk levels sectors.

The Brazilian government through its Ministry of Cities and the Institute for Technological Research (Instituto de Pesquisas Tecnológicas – IPT) developed a landslide risk mapping methodology that we are calling the Brazilian Government Methodology (BGM) to map landslides and river-bank erosion risk (Carvalho, Macedo, & Ogura, 2007). Within the BGM, two technicians do field inventory, observing local geo-environmental variables, and based on their previous experience and personal observation, they decide on the level of risk. This mapping is biased since it does not involve any objective mathematical computation and is influenced by each technician's personal experience.

The purpose of this study is to discuss and compare the performance of two methodologies that quantifies the BGM and automatically classify the risk level of shallow landslide prone-areas. The first methodology is based on the Analytical Hierarchical Process (AHP) and it is heuristic/expert based. The second is statistically-based and uses Ordinal Logistic Regression (OLR). We compared how similar their risk level classifications are and how similar they are with the BGM. Additionally, we are using a user-friendly application (app) developed by the authors, that computes the level of risk and it can be used on a tablet, smartphone, or computer with internet access or with RStudio software installed. Both methodologies can use the app since the classifiers are both based on the BGM.

METHODOLOGY

DATASET

The dataset is part of the 2010 Sao Paulo landslide and river bank erosion risk mapping done by the Instituto de Pesquisa Tecnologico (IPT) and Sao Paulo Municipality employing the BGM. We reduced the original 11,789 to 754 sectors based, in which just shallow landslides were considered. After, we random divided the dataset as training (70%) and test (30%) sets.

ORDINAL LOGISTIC REGRESSION

Ordinal Logistic Regression is commonly used in medical, epidemiologic, educational, and psychological studies, in which the y variable (response variable) represents levels, such as low, moderate, and high and the x variables (predictor variable) can be categorical (ordinal or not), discrete, and continuous. In the BGM, there are four risk levels: low, moderate, high, and very high. Figure 1 illustrates the steps of the OLR methodology.

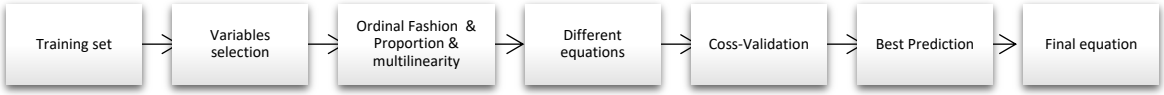


Figure 1 – Ordinal Logistic Regression flowchart

ANALYTICAL HIERARCHICAL PROCESS (AHP)

AHP has been commonly used as a decision support tool and relies on experts' knowledge and their pairwise comparison of the contributing variables to compute classifier weights (Saaty, 2008; Kousalya et al., 2012). Computing the classifier weights is a process that involves selecting the classifiers and building a hierarchical structure with them, designing a questionnaire with pairwise comparisons, selecting and delivering them to experts in the field, and checking the responses for consistency.

RESULTS

ORDINAL LOGISTIC REGRESSION

The test set was best predicted by Equation 3 (79.2%), followed by Equation 5 (76.8%), Equation 1 (76.0%), Equation 4 (75.2%), and Equation 2 (74.4%). However, the prediction of the five equations were not so significant different (*Mean = 76.32, SD=1.84, Range = 4.8*). Better performance of Equation 3 can be partially explained by the number of predictors. Threshold values from R1 to R2 (-0.74), R2 to R3 (4.20), and R3 to R4 are ordinal. The very high threshold between R3 and R4 is expected. Very high risk level (R4) is observed in risk sectors with signs of instability, like features that indicate movement in the terrain. Cracks in the wall or in the terrain, poles and trees tilted, or leaning walls are some examples. Also, these sectors can have landslide scars; which means past landslide occurred in these sectors.

ANALYTICAL HIERARCHICAL PROCESS (AHP)

The total of experts involved were 23 but for each classifier weight value, we used 7 to 13 experts do to the CR (*AVERAGE=9.77, SD=2.17*). The weight value of classifiers is higher for instability category when compared with anthropogenic and natural. In this analysis, we consider classifiers with weight values higher than 7.5 high value, a weight value between 3 and 7.5 moderate value, and weight values lower than 3 low value. The downward floor has the highest weight value (16.87), followed by landslide scars (12.64); both classifiers are in the instability category. Moreover, other instability classifiers have a higher weight value than classifiers from anthropogenic and natural categories. Instability category includes classifiers that indicate landslide initiation (i.e. downward floor) or past landslide (landslide scars), which are expected to be observed at a very high-risk level. Some of the slope angle classifiers are the ones with the highest weight values, like $\alpha = 90$ (5.85) and $60 \leq \alpha < 90$ (5.69). However, $\alpha = 90$ is not found in natural slope for shallow landslides. In the natural category, slopes with geology or soil favorable that contributes to unstable slopes have a moderate weight value, 4.65 and 4.72, respectively. Classifiers from anthropogenic category have lower specific weight, but some classifier, like garbage (3.88) and houses made of mix material (3.60) and wood (3.15) have a moderate specific weight. Thresholds between one risk level and another were computed using training set with a total of 530 shallow landslide risk sectors of Sao Paulo. For each sector, we use input data collected in the field and we computed a risk value. We plot a density histogram and used kernel density estimation to display normal distribution, and each normal distribution represents one risk level ($R1 < 31$, $31 \leq R2 < 49$, $49 \leq R3 < 69$, $R4 > 69$).

CONFUSION MATRIX

Based on three confusion matrix, OLR quantifies the level of the risk more similar to the BGM when compared with AHP. Experts based methodology is less conservative than OLR and BGM, classifying the level of risk lower than both methodologies.

CONCLUSIONS AND FURTHER WORK

Classifying quantitatively and qualitatively the landslides risk areas in urban area in Brazil is not an easy task, due to specificity of each sector. There are some aspects that are similar, like overall precarious and self-engineering dwellings. However, each dwelling and sector have their one particularity and are constantly changing. The developed application can help map these risk sectors and diminish the bias during the mapping. For future, being able to take photos using the application and manual drawing the risk sectors boundaries using a map would improve data collection.

REFERENCES

Agresti, Alan (2011) Examples of Using R for Modelling Ordinal Data. In *Analysis of Ordinal Categorical Data*, 2nd ed., Wiley.

Akgun, A., & Türk, N. (2010). Landslide susceptibility mapping for Ayvalik (Western Turkey) and its vicinity by multicriteria decision analysis. *Environmental Earth Sciences*, 61(3), 595–611. https://doi.org/10.1007/s12665-009-0373-1

Akgun, A. (2012). A comparison of landslide susceptibility maps produced by logistic regression, multi-criteria decision, and likelihood ratio methods: a case study at Izmir, Turkey. *Landslides*. 9: 93. https://doi.org/10.1007/s10346-011-0283-7

Ayalew, L., Yamagishi, H., Marui, H., & Kanno, T. (2005). Landslides in Sado Island of Japan: Part II. GIS-based susceptibility mapping with comparisons of results from two methods and verifications. *Engineering Geology,* 81(4), 432–445. https://doi.org/10.1016/j.enggeo.2005.08.004

Barredo, J., Benavides, A., Hervás, J., & van Westen, C. J. (2000). Comparing heuristic landslide hazard assessment techniques using GIS in the Tirajana basin, Gran Canaria Island, Spain. *International Journal of Applied Earth Observation and Geoinformation*, 2(1), 9–23. https://doi.org/10.1016/S0303-2434(00)85022-9

Baas, S., Ramasamy, S., Pryck, J. D. de, & Battista, F. (2008). *Disaster risk management systems analysis - A guide book*. Rome: FAO. Retrieved from http://www.fao.org/docrep/011/i0304e/i0304e00.HTM

Balza, Guillherme (2008, December 16). Chuva em Santa Catarina mata mais de 120 pessoas; tragédias naturais castigam vários pontos do mundo, *UOL Notícias*, retrived from https://noticias.uol.com.br/especiais/retrospectiva-2008/ultnot/2008/12/16/ult7037u9.jhtm

CEPED UFSC. (2013). *Atlas Brasileiro de Desastres Naturais: 1991 a 2012*. Florianópolis: CEPED UFSC.

Corominas, J., van Westen, C., Frattini, P., Cascini, L., Malet, J. P., Fotopoulou, S., … Smith, J. T. (2014). Recommendations for the quantitative analysis of landslide risk. *Bulletin of Engineering Geology and the Environment*, *73*(2), 209–263. http://doi.org/10.1007/s10064-013-0538-8

Das, I. C. (2011). *Spatial statistical modelling for assessing landslide hazard and vulnerabiity.* Enschede, TheNetherlands: ITC - Faculty of Geo-information science and earth observation - University of Twente.

Dourado, F., Arraes, T. C., & Silva, M. F. (2012, Dec). O Megadesastre da Região Serrana do Rio de Janeiro - as causas do evento, os mecanismos dos movimentos de massa e a distribuição espacial dos investimentos de reconstrução no pós-desastre. *Anu. Inst. Anu. Inst. Geocienc., 35*(2), pp. 43-54.

Gorsevski, P. V., Jankowski, P., & Gessler, P. E. (2006). An heuristic approach for mapping landslide hazard by integrating fuzzy logic with analytic hierarchy process. *Control and Cybernetics*, 35(1), 121–146.

Hasekioğulları, G. D., & Ercanoglu, M. (2012). A new approach to use AHP in landslide susceptibility mapping: a case study at Yenice (Karabuk, NW Turkey). *Natural Hazards*, 63(2), 1157–1179. https://doi.org/10.1007/s11069-012-0218-1

Harrell, F. E. (2015). *MulticlassifierModeling Strategies: With applications to Linear Models, Logistic and Ordinal Regression, and Survival Analysis*. Second Edition, Spriger. https://doi.org/10.1007/978-3-319-19425-7_4

Highland, L.M., and Bobrowsky, Peter, 2008, *The landslide handbook—A guide to understanding landslides*: Reston, Virginia, U.S. Geological Survey Circular 1325, 129 p.

IBGE (2018). *População em áreas de risco no Brasil*. Instituto Brasileiro de Geografia e Estatística. Rio de Janeiro. Retrieved from: https://agenciadenoticias.ibge.gov.br/media/com_mediaibge/arquivos/6d4743b1a7387a2f8ede699273970d77.pdf

IDRE (2019). ORDINAL LOGISTIC REGRESSION | R DATA ANALYSIS EXAMPLES. UCLA. Retived from: https://stats.idre.ucla.edu/r/dae/ordinal-logistic-regression/

IPT (2010). *Mapeamento de Áreas de Risco – São Paulo*

Keller, Edward (2011). *Environmental geology*, 9th Edition, Upper Saddle River, Person Prentice Hall.

Maricato, E. (2008). *Brasil, cidades: alternativas para a crise urbana.* Petropolis, RJ: Vozes.

Ministério das Cidades (June 2008). *Ministério das Cidades.* Retrieved from https://www.cidades.gov.br/

Mondal, S., & Maiti, R. (2012). Landslide Susceptibility Analysis of Shiv-Khola Watershed, Darjiling: A Remote Sensing & GIS Based Analytical Hierarchy Process (AHP). *Journal of the Indian Society of Remote Sensing*, 40(3), 483–496. https://doi.org/10.1007/s12524-011-0160-9

Phukon, P., Chetia, D., Das, P., 2012. Landslide susceptibility assessment in the Guwahati City, Assam using Analytic Hierarchy Process (AHP) and Geographic Information System (GIS). *International Journal of Computer Applications in Engineering Sciences* 2 (1), 1–6.

Pourghasemi, H.R., Pradhan, B., Gokceoglu, C., 2012. Application of fuzzy logic and analytical hierarchy process (AHP) to landslide susceptibility mapping at Haraz watershed, Iran. *Natural Hazards* 63 (2), 965–996.

Saaty, T. L. (1980). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26.

Saaty, T. L. (1990). How to make a decision: The Analytic Hierarchy Process. *European Journal of Operational Research*. https://doi.org/10.1016/0377-2217(90)90057-I

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83. https://doi.org/10.1504/IJSSCI.2008.017590

Saaty, T. L., & Vargas, L. G. (1987). Uncertainty and rank order in the analytic hierarchy process, *32*, 107–117.

Sedan, A. H., & Suv, C. (2013). Analytic hierarchy process. *Power Point Presentation*, 1–22. https://doi.org/10.1002/9781118644898.ch2

Tominaga, L. K., Santoro, J., & Amaral, R. (2009). *Desastres naturais: conhecer para prevenir.* Sao Paulo: Instituto Geologico.

UOL (2019). Chuva em Santa Catarina mata mais de 120 pessoas; tragédias naturais castigam vários pontos do mundo. Retrieved from https://noticias.uol.com.br/especiais/retrospectiva-2008/ultnot/2008/12/16/ult7037u9.jhtm

van Westen, C. J., van Asch, T. W. J., & Soeters, R. (2006). Landslide hazard and risk zonation - Why is it still so difficult? *Bulletin of Engineering Geology and the Environment*, *65*(2), 167–184. http://doi.org/10.1007/s10064-005-0023-0

Wu, C. H., & Chen, S. C. (2009). Determining landslide susceptibility in Central Taiwan from rainfall and six site factors using the analytical hierarchy process method. *Geomorphology*, 112(3–4), 190–204. https://doi.org/10.1016/j.geomorph.2009.06.002

Yalcin, A. (2008). GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): Comparisons of results and confirmations. *Catena*, 72(1), 1–12. https://doi.org/10.1016/j.catena.2007.01.003

Yalcin A, Reis S, Cagdasoglu A, Yomralioglu T (2011) A GIS-based comparative study of frequency ratio, analytical hierarchy process, bivariate statistics and logistics regression methods for landslide susceptibility mapping in Trabzon, NE Turkey. *Catena* 85:274–287

Analysis of Japanese Tweets about 2018 Typhoon Jebi by Creating Co-occurrence Networks

Sanetoshi Yamada
Tokai University
S.Yamada@star.tokai-u.jp

Keisuke Utsu
Tokai University
utsu@utsuken.net

Osamu Uchida
Tokai University
o-uchida@tokai.ac.jp

INTRODUCTION

Prompt and accurate collection/distribution of information is important to minimize damage due to a large-scale disaster. The utilization of social media, particularly Twitter, during a disaster has attracted worldwide attention (Imran et al., 2015). The number of tweets increases explosively during a large-scale disaster. For example, on the day of the Great East Japan Earthquake, approximately 33 million tweets were posted. In the 10 minutes after the Northern Osaka Earthquake hit Japan on June 2, 2018, more than 270,000 tweets that contained the word "地震" (earthquake, in Japanese) were posted (Yamada et al., 2018). Therefore, to effectively utilize Twitter during a disaster, it is important to analyze the characteristics of tweets. In this study, we analyze Japanese tweets posted when 2018 Typhoon Jebi, one of the strongest typhoons that landed in Japan in the past, was approaching and striking Japan. Specifically, we create co-occurrence networks to visualize what kind of tweets have been posted a lot. We also develop an application that displays the position of the typhoon, precipitation, and the co-occurrence network simultaneously.

METHODOLOGY

Tweet Dataset

2018 Typhoon Jebi (Typhoon No. 21) caused extensive damage, particularly in the Kansai region such as Osaka, Japan. In this study, we analyze Japanese tweets about 2018 Typhoon Jebi that were posted between Sept. 3rd and 5th, 2018 and contained the word "台風" (typhoon, in Japanese). These tweets were collected by using the Twitter Search API by ourselves (6,096,493 tweets).

Co-occurrence Network Diagram

We make co-occurrence network diagrams of words used in the tweets for a better understanding of target tweet contents. This paper focuses on the word "上陸" (landing), which is a word not commonly used under normal circumstances (Japan Meteorological Agency defines "landing" when the center of a typhoon reaches the coastline of the main territory of Japan).

Application to display the position of the typhoon and the co-occurrence network

We develop an application that simultaneously displays the position of the typhoon, the precipitation distribution, and the co-occurrence network of the tweet at the analysis target time to facilitate understanding the relationship between inclement weather, the extent of damage, and tweets. In this study, we obtain the location of the typhoon from Digital Typhoon (http://agora.ex.nii.ac.jp/digital-typhoon/) and the amount of precipitation at each location from the Japan Meteorological Agency, respectively.

RESULTS

Figure 1 shows the co-occurrence network obtained from the original tweets (tweets that are not retweets) that contain "上陸" posted between 12:00 JST and 13:00 JST on Sept. 4th (3,237 tweets). In Fig. 1, the size of the circles indicates the word frequency. The direction of the arrows indicates that words are connected in that direction. Thicker arrows indicate more tweets and stronger arrow colors indicate a stronger relationship. As can

be seen from Fig. 1, many tweets referred to "Typhoon Jebi (Typhoon No. 21) landed on the southern part of Tokushima Prefecture." Moreover, we can find the important content that "a man repairing a roof in Itano town was injured," although the number of tweets mentioning is small.

Next, we developed an application that simultaneously displays the position of the typhoon, precipitation distribution, and co-occurrence network of the tweets. Figure 2 shows examples of the developed application screen. By changing the options on the top of the screen, the application can also display the results for a particular time one wishes to analyze. By using this function, the transition of tweet content can be identified interactively. Moreover, as well as the time, we can change the words to focus on.

CONCLUSIONS AND FURTHER WORK

We created co-occurrence networks of Japanese tweets about 2018 Typhoon Jebi to analyze and visualize what kind of tweets have been posted a lot. We also develop an application that displays the position of the typhoon, precipitation, and the co-occurrence network simultaneously. We collected tweets about the 2018 Typhoon Trami which also caused huge damage to Japan; therefore, we plan to compare the content of those tweets and tendencies in emoji usage in the future. Note that while the application developed for this study visualizes analysis results of already collected tweet data, we would like to build a system that displays analysis result in real time during a disaster in the future.

ACKNOWLEDGMENTS

This study was supported by JSPS KAKENHI (Grant Number 18K11553) and Tokai University General Research Organization.

REFERENCES

Imran, M., Castillo, C., Diaz, F., and Vieweg, S. (2015) Processing Social Media Messages in Mass Emergency: A Survey, *ACM Computing Surveys*, 47, 4, article 67.

Yamada, S., Utsu, K., and Uchida, O. (2018) An Analysis of Tweets During the 2018 Osaka North Earthquake in Japan - A Brief Report, *Proceedings of the 5th International Conference on Information and Communication Technologies for Disaster Management*, Sendai, Japan.

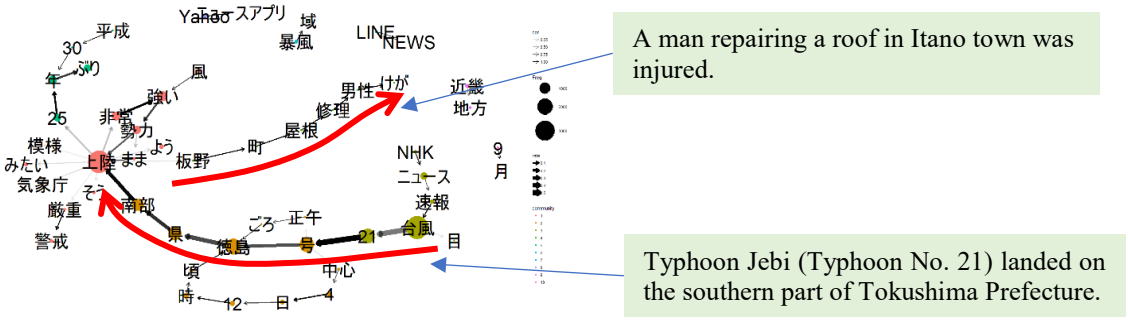


Figure 1. Co-occurrence network of tweets posted between 12:00 and 13:00 on Sept. 4, 2018

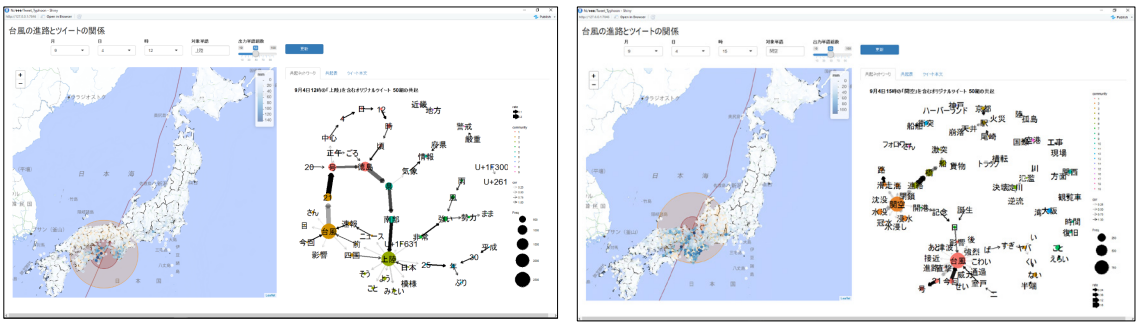


Figure 2. Simultaneous display of the position of the typhoon, the precipitation, and the co-occurrence network

Standardization for an enhanced crisis management

René Lindner
DIN e. V.
rene.lindner@din.de

INTRODUCTION

The poster "Standardization for an enhanced Crisis Management" is describing the standardization activities within the research project DRIVER+ (Driving Innovation in Crisis Management for European Resilience). The integration of standardization in research and innovation projects is increasing and a well-established path and approved methodology that supports the integration of standardization in the projects is needed. This will address the need of the projects to exploit and disseminate the project findings with a suitable tool. DIN as standardization body is part of this project in which more than 30 partners work jointly to demonstrate and test crisis management solutions. Therefore the poster provides information on the project itself, the standardization methodology used within the frame of the project, the proposals for new standards as well as the possibility to join the standardization activities, the project related crisis management network CMINE and the future usage of the standardization work conducted in the project.

METHODOLOGY

The standardization activities within the DRIVER+ project have been led by DIN, the German Institute for Standardization. The main reason for the involvement of DIN is the possibility to exploit the standardization potentials out of the DRIVER+ results and to transfer these directly into new standardization activities. Therefore an integrative approach was used, with analyzing existing standards and assessing the standardization needs and potentials of the project by evaluating 1) the needs of the market and end-users in crisis management *(Demand side) a*nd 2) the DRIVER+ results being able to be transferred into a standard (considering various selection criteria) and any other relevant existing standard *(Supply side)*. The outcome of this assessment with the support of a dedicated workshop to support the identification of standardization ideas were several proposals for new standards (e.g. CEN Workshop Agreements).

RESULTS

Out of the first phase of the development of standards within the DRIVER+ project, three different CEN Workshops have been initiated: 1) Requirements on information exchange across borders and organizations; 2) Trial Guidance Methodology; 3) Building a Common Simulation Environment. For the upcoming standards development phase the concept of integrating several different stakeholders and especially end-users is of high importance. In this regard the *Community of Practice* network CMINE (Crisis Management Innovation Network Europe) is supporting the interaction with and integration of project internal and external organizations in the standardization activities.

CONCLUSIONS AND FURTHER WORK

The integration of standardization activities in research and innovation projects such as DRIVER+ supports the dissemination and exploitation of project findings, raises awareness on existing relevant standards and fosters the initiation of new standardization activities to which project externals are highly invited to contribute to. The approval of the methodology to integrate standardization in DRIVER+ and other research projects via survey and lessons learned assessment is planned. For the standards currently being developed, every organization interested to join one of the three above mentioned standardization activities are invited to contact the project.

ACKNOWLEDGMENTS

The DRIVER+ project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 607798.

REFERENCES

CEN BOSS Website (2019) CEN Workshop Agreement, https://boss.cen.eu/developingdeliverables/CWA/Pages/default.aspx

Lindner, R., Sarriegi, J.M. and Hernantes, J. (2018) Standardization process for urban resilience, *Proceedings of the 11th International Forum on Urbanism IFOU*, Barcelona, https://sciforum.net/paper/view/conference/5981.

Constructing Trust in Disaster Communications

Yuko Murayama
Tsuda University
murayama@tsuda.ac.jp

INTRODUCTION

The Great East Japan Earthquake on March 11th, 2011 caused severe damage to the northern coast of the main island in Japan. Since then we have been working to help out the affected area in terms of IT support such as internetworking and providing PCs. Through our support activities we came across an interesting issue concerning collaboration with people from heterogeneous backgrounds. Those people who worked on the disaster response came from different backgrounds and most of them were doing quite different tasks from what they usually did before the disaster. Disagreements and distrust happened quite easily. We call this problem disaster communications in this paper. We found that trust plays an important role in such communications.as well as how possibly we could construct trust based on the Salient Value Similarity (SVS) Model. In this paper we report our experiences during our support activities and our findings in terms of trust.

METHODOLOGY

We received a request from people in Tokyo indicating that some companies located in the Tokyo area would like to know where they could possibly send PCs and printers for use in disaster support. A group of engineers from academia and industry also offered to help set up data networking in the affected area. They needed to know where they could provide the equipment and network services. We contacted the emergency response headquarter of Iwate prefecture for information and suggestions about providing the coast area with network services and PCs. Moreover, we came to know the people in the large volunteer center (VC) in Tohno City located next to the affected coastal cities. Tohno City did not suffer as much from the Tsunami and was useful to support the disaster locations. In the end, we organized a loosely coupled federation of projects, organizations and people.

According to National Research Council (National Research Council,1989) risk communications is "an interactive process of exchange of information and opinion among individuals, groups, and institutions." Risk communications have been studied to a great extent (Reynolds, B. and Seeger, M.W., 2005), but focused mainly on the future risks. On the other hand, disaster communications are more immediate in dealing with real incidents; they are considered as a part of emergency management (Hilz, S. R. et al., 2009).

Disaster communications include many different entities such as sufferers, volunteers, administrative offices and supporters from organizations or by individual. All of them have different viewpoints and different background. For disaster support, they need to discuss the issues on the same table. They would have the same purpose but it might be hard to cooperate with each other. From our experiences, disaster communications have the following nature:

1. Heterogeneity of people
2. Most of us are novices
3. Communications with unknown people
4. Need for decision-making in changing circumstances
5. None knows the true needs
6. Don't expect appreciation

To better understand the implications of operating in this space we look to the Elaboration Likelihood Model (ELM) from psychology (Petty, R. E. and Cacioppo, J. T., 1981). According to the model, when we receive Persuasive Communication, such as a commercial message for a car, if we are interested in knowing more about the car in question (Motivated to Process) and knows much about cars (Ability to Process), we could decide to

accept the initial message or not by ourselves (Process with Central route). However, if one is not interested in the car, or does not know much about cars, then one would not look back at the initial message content, but would decide to accept the message or not according to environmental issues such as who sent this message or the way in which it is presented (Process with Peripheral Route).

For disaster communications we often need to process with the peripheral route and so need to be able to assess our trust in the source.

RESULTS

In the beginning of our support activities, most of us working in the information science and engineering area assumed that information and communication technology would be required desperately, however, the truth was that it was not so. We presumed the providers' viewpoint. What was really needed in the first place was support personnel and cars with drivers; moreover, a person who could listen to the people in the suffered area, as well.

According to the Salient Value Similarity (SVS) (Earle, T. C. and Cvetkovich, G., 1995). If one shared a salient value with someone else, we could trust someone. The question is how exactly we could share such a value at disaster. Eight years ago in a shelter, firstly we were asked to provide cars and helpers and we provided a helper. Next, they asked for a copier and we provide the one. Whatever was requested, when we showed our intention to provide what was needed. Gradually the managers of the shelter thought that they shared a salient value with us. Sharing the salient value might have been possible based on such transactions with requests and positive replies. We did not provide a hundred percent of what we were asked for, yet we succeeded in constructing trust. Our hypothesis is that transactions with requests and positive replies are important for the counterparts to presume they share a salient value with us so that they construct trust in us.

CONCLUSIONS AND FURTHER WORK

In this paper, we reported our experiences from our support activities just after the Tohoku earthquake and tsunami on March 11th, 2011 and our initial work on disaster communications derived from our experiences. Quite often officers in local governments as well as some in the prefectural emergency response headquarters office, regard that fairness is most important in the management of support. On the other hand, from our experience, what we needed for disaster communications included speed, rhythm and trust. We needed speed, because everyone expects a prompt reply. The best that we could do is to start creating whatever was requested and inform the requestor that we were working on it, so that the requester would feel the request was being addressed. We need rhythm in our activity so that even when we receive almost impossible request, we would have some way to deal with it.

From our experiences what we required was speed, rhythm and trust in disaster communications. In our previous work, we lead that the trust is required in disaster communications based on ELM. Moreover, using the SVS model, we came up with the hypothesis that speed and rhythm in disaster communications could lead to construct trust. We could possibly show the hypothesis in a heuristics way in future by try and use such communications at disaster response.

ACKNOWLEDGMENTS

I appreciate the cooperation with the people throughout the emergency response eight years ago in Iwate. In particular, I thank Yushi Oyama, Shuzo Koshino, Shinji Akitomi and Shuichi Takamatsu.

REFERENCES

Earle, T. C. and Cvetkovich, G. (1995) Social trust: Toward a cosmopolitan society. Westport, CT: Praeger Press.

Hilz, S. R. et al. (2009) The domain of emergency management information, in Information systems for emergency management, Van de Walle, B.,Turoff, M. and Hiltz, S.R.eds 3-20.

National Research Council (1989) Improving risk communication, National Academy Press.

Petty, R. E. and Cacioppo, J. T. (1981) Attitudes and persuasion: Classic and contemporary approaches, Dubuque, IA: William C. Brown.Agarwal, R. and Karahanna, E. (2000) - Time Flies when You're having Fun: Cognitive Absorption and Beliefs about Information Technology Usage, *MIS Quarterly*, 24, 4, 665-694.

Gathering Local Knowledge for Disaster Risk Reduction: The Use of Sketch Maps in Group Discussions

Carolin Klonner
Institute of Geography, Heidelberg, Germany
c.klonner@uni-heidelberg.de

Luca Blessing
Institute of Geography, Heidelberg, Germany
luca.blessing@stud.uni-heidelberg.de

INTRODUCTION

Participatory approaches can be applied to investigate the geospatial knowledge and risk perception of citizens in disaster-affected regions. Knowledge gained this way can improve, for example, the precision of official risk maps for specific locations. A dialogue between researchers, citizens, and centers of expertise can be established, which enables exchange around recommendations for measures of disaster risk reduction on a local level. The presented approach is based on previous studies about the use of sketch maps for disaster risk reduction (Klonner et al. 2016; Klonner et al. 2018). These previous studies and related methods are further developed so that they can be used for group discussions. In this way, citizens can be involved in the whole disaster reduction process, which can help to motivate them to take own mitigation measures. In addition to Bustillos Ardaya et al. (2019), who also applied large maps in a similar way, our approach offers automatic georeferencing and color detection. This enables a fast processing of the data and efficient use for disaster management. Moreover, the approach is paper-based in order to include marginalized groups, which do not have knowledge of specific technologies or access to the internet.

METHODOLOGY

We apply a participatory approach to capture geospatial local knowledge. This method is based on a cartographic map in which inhabitants of flood-affected regions mark their flood risk perception with colored pens or stickers. Additionally, they can mark elements at risk as well as flood levels of historic flood events, which they experienced. If stickers are used, other groups can even reuse the base maps. These sketch maps are used in a DIN A0 format in order to allow their utilization in group discussions. In this way, people can share their knowledge, mark it on the common map, and thus, gather and combine their local knowledge. The discussions during the elaborations are valuable additional insights into the priorities of the participants who were already affected by disasters and are likely to be affected again. Furthermore, the communication can unveil information that a participant might not have mentioned in an individual interview. The evaluation can lead to more adequate disaster risk reduction measures for this specific region, and makes it possible to develop risk perception maps and to identify areas at risk, especially in areas, where no other risk maps are available.

We aim at providing a sustainable approach for the use by local governments, and thus, only little technical knowledge and equipment is required for the application. The DIN A0 maps consist of DIN A4 pages that are glued together. Furthermore, we use open source software to allow for availability of the tools also for communities with limited resources. We apply OpenStreetMap Field Papers as the base map of the sketch maps, and for the color detection we use the Open Source Computer Vision Library (OpenCV). The analysis of the geospatial information captured via the sketch maps is performed with the geo-information system QGIS. The easy-to-use paper-based method can be applied in the field, during workshops, in schools or community centers, and does not require battery or internet connection. Pictures of the sketch maps can be uploaded to the Field Paper homepage at a later date, where they are automatically georeferenced, and the resulting GeoTIFFs can be downloaded to QGIS. We use an automatic color detection, which saves a lot of time and avoids errors in comparison to manual digitizing of the participants' marking. The marking is stored in a separate vector file for further analyses in a GIS.

RESULTS

We applied the sketch maps for group discussions in Eberbach, Germany, which is regularly flooded by the Neckar river. Citizens were asked to mark the maximum water level they experienced (orange), the normal overflow (red) and elements at risk (blue). The participants discussed and exchanged their experiences and as soon as they agreed on the specific area, one of them marked it on the map (Figure 1). After the automatic georeferencing of the sketch maps and the download to QGIS, the marking of the sketch maps was automatically detected via the newly developed approach and saved in a separate vector shape file.

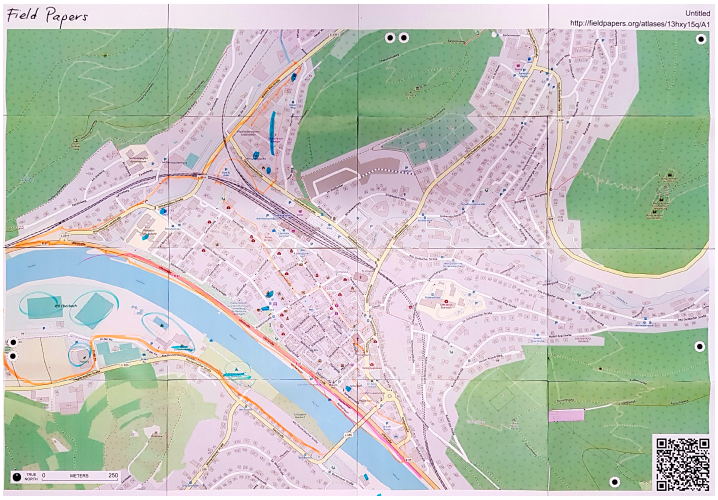


Figure 1: Sketch map of a group of four people who marked the maximum water level they experienced (orange), the normal overflow (red), and elements at risk (blue).

CONCLUSIONS AND FURTHER WORK

The results of the pilot study show that our approach of group sketch maps is an easy-to-use method, which works well for both capturing detailed local knowledge and visualizing this knowledge automatically. The information exchange during the group discussions led to very detailed markings. We will use this approach for further research in different flood-affected study areas in Brazil.

In addition to capturing local knowledge about floods, the presented approach can be adapted to different natural and anthropogenic hazard types. Moreover, beyond the use in research, the method is also applicable by practitioners. The use of sketch maps in group discussions offers to capture and visualize local information, for example, about elements at risk, flood risk perception as well as flood level estimation based on the experiences of the citizens. This local information can be combined with data provided by centers of expertise or local authorities such as historical data, models, and risk maps.

ACKNOWLEDGEMENTS

The research project is funded by the Belmont Forum and NORFACE joint programme Transformations to Sustainability (T2S) and by the Federal Ministry of Education and Research in the field of social-ecological research. We thank the city council and the citizens of Eberbach for their support of and participation in the project.

REFERENCES

Bustillos Ardaya, A., Evers, M. and Ribbe, L. (2019): *Integrated Participatory Methodologies for Disaster Risk Reduction: Tools to Analyze Complex Systems Through Participatory Processes in Brazil*. In: Nehren U., Schlüter S., Raedig C., Sattler D. and Hissa H. (eds.): Strategies and Tools for a Sustainable Rural Rio de Janeiro. Springer International Publishing, pp. 361-376.

Klonner, C., Marx, S., Usón, T. and Höfle, B. (2016): Risk Awareness Maps of Urban Flooding via OSM Field Papers- Case Study Santiago de Chile. In: *Proceedings of the ISCRAM 2016 Conference*. Rio de Janeiro, Brazil, pp. 1-14.

Klonner, C., Usón, T.J., Marx, S., Mocnik, F.-B. and Höfle, B. (2018): Capturing Flood Risk Perception via Sketch Maps. *ISPRS International Journal of Geo-Information*. Volume 7, pp. 359; doi:10.3390/ijgi7090359.

Towards a comprehensive architecture to extract situational models from Twitter data

Julien COCHE
IMT Mines Albi
julien.coche@mines-albi.fr

Aurelie MONTARNAL
IMT Mines Albi
aurelie.montarnal@mines-albi.fr

Andrea TAPIA
PennState University
atapia@ist.psu.edu

Frederick BENABEN
IMT Mines Albi
frederick.benaben@mines-albi.fr

INTRODUCTION

Crisis situations require specific information to organize and respond to the events. The need of information is important and emergency management cells aim at gathering them as much as possible to build a common operational picture (COP) of the field. Also, citizens are using more and more social media to share what is happening around them during exceptional events. As (Justine I. Blanford et al. 2014) shows, citizens tend to send more messages during crisis situations. Social media, such as Twitter, Facebook or Instagram therefore participate in the exchange of information related to the crisis. Consequently, it is important to be able to take advantage of this by integrating citizens' social media data into the decision-making process.

Up to this day, many tools exist in the literature. However, information systems integrating social media data into the COP are rarely used in the facts because they are still resource-consuming. This leads to a paradoxical situation where decision-makers are looking for information to organize their resources while victims and witnesses' willing to share information is not taken into account by rescue organizations. Also, (Imran et al. 2018) points out some possible necessary improvements. Among them, "*how the added-value information extracted thanks to such social media-oriented system should be integrated in the decision-making process?"* echoes to this context.

Consequently, **how to fully integrate the information provided by social media data, in times of crisis, to improve the common understanding and thus the collaborative response of the responders?**

METHODOLOGY

The proposed approach relies on an understanding of the rescue organization by the algorithms. In (Kropczynski et al. 2018) authors highlight that in the American 911 call centers, staff are asking questions in order to answer the "6Ws" (What, When, Weapon, Why, Where and Who). Any answer related to one of these questions is then forwarded to the emergency teams. Assuming that they are taking decisions according to a specific set of concepts environment, resources, people involved, possible additional threats etc. It may be possible to map these concepts within the stream of social media data and, make the algorithm "understand" the corresponding extracted information.

Many people proposed metamodels or ontologies that cover concepts involved during an emergency. (Bénaben et al. 2016) introduces a metamodel focused on supporting the collaboration between crisis stakeholders. Its purpose is to describe the activities they carry out with each other in order to respond to the better way to the crisis.

Based on the metamodel, the approach proposed here is to couple a classifier that will help mining the information within the social media data stream and a metamodel to make sense of them thanks to well-known concepts. Doing so, it would be easier to monitor the operations and feed the COP. The classifier role would be to capture the data relative to the metamodel's classes and then, instantiate the them. This study is proposed for Tweets data flows as they remain the most accessible thanks to the use of the Twitter Application Programming Interface[1].

[1] https://developer.twitter.com/en/docs/api-reference-index

RESULTS

Hence, the proposed solution to our research question is composed of a classifier alongside a metamodel. While this solution allows the classifier to identify data which contains the concepts the responders are interested in, several challenges are ahead. The classifier needs to "reconcile" the data it receives, with the metamodel classes, in order to instantiate the classes. To do so, the classifier requires a text representation that keeps enough context to decide if this tweet, or this set of words (i.e. parts of tweets), relates to a class of the metamodel. This 'contextual' word representation should be handled first by a word embedding. Word embeddings represent word tokens through vectors according to the surrounding context of each word. Word embeddings are relevant if their vocabulary is sufficiently extensive, otherwise they encounter too many out-of-vocabulary words. Moreover, domain-specific embeddings face the lack of relevant training data too obtain large enough volume. (Karisani et Agichtein 2018) proposes as a solution to use a general-purpose word embedding with adjustments. Their solution is based on emphasizing the terms most related to their domain.

Then, having contextualized all textual tokens, the classifier must properly aggregate them and label the corresponding extracted information according to the metamodel. To do so, the system will use a clustering algorithm that still has to be chosen depending on a benchmark, that will be applied to the n-dimensional results of the word embedding. That way, clusters of words will be mapped to the concepts of the metamodel. The distance formula for the clustering algorithm will have to take several elements into account such as: a predefined relevant time window, a semantic proximity or a geographical source of data proximity.

CONCLUSIONS AND FURTHER WORK

This paper presents a novel social media analysis system which aims to integrate further the information collected on social media during a crisis into the decision-making process. The problematic raised at the beginning is: how to fully integrate the information provided by social media data, in times of crisis, to improve the common understanding and thus the collaborative response of the responders?

Future work will consist in both experimentation and implementation. Moreover, further work may lead to try to merge the data coming from social media and data coming from sensors available on the field (water level, CCTV…). Also, this work is not dedicated only to crisis cells and results may be reused in humanitarian supply chain management, to extract the different stakeholders thanks to previous records.

REFERENCES

Bénaben, F., M. Lauras, S. Truptil, et N. Salatgé. 2016. « A Metamodel for Knowledge Management in Crisis Management ». In *2016 49th Hawaii International Conference on System Sciences (HICSS)*, 126-35. https://doi.org/10.1109/HICSS.2016.24.

Imran, Muhammad, Carlos Castillo, Fernando Diaz, et Sarah Vieweg. 2018. « Processing Social Media Messages in Mass Emergency: Survey Summary ». In *Companion of the The Web Conference 2018 on The Web Conference 2018 - WWW '18*, 507-11. Lyon, France: ACM Press. https://doi.org/10.1145/3184558.3186242.

Justine I. Blanford, Jase Bernhardt, Alexander Savelyev, Gabrielle Wong-Parodi, Andrew M. Carleton, David W. Titley, et Alan M. MacEachren. 2014. « Tweeting and Tornadoes ». In *ISCRAM 2014 Conference Proceedings – 11th International Conference on Information Systems for Crisis Response and Management*, édité par M S Pfaff S.R. Hiltz, 319-23. University Park, PA: The Pennsylvania State University. http://idl.iscram.org/files/blanford/2014/328_Blanford_etal2014.pdf.

Karisani, Payam, et Eugene Agichtein. 2018. « Did You Really Just Have a Heart Attack?: Towards Robust Detection of Personal Health Mentions in Social Media ». In *Proceedings of the 2018 World Wide Web Conference*, 137–146. WWW '18. Republic and Canton of Geneva, Switzerland: International World Wide Web Conferences Steering Committee. https://doi.org/10.1145/3178876.3186055.

Kropczynski, Jess, Julien Coche, Eric Obeysekare, Frederick Bénaben, Rob Grace, Shane Halse, Aurélie Montarnal, et Andrea Tapia. 2018. « Identifying Actionable Information on Social Media for Emergency Dispatch », 11.

A Filtering and Visualization Workbench for Messages in Crisis Management

Jan Blume
Fraunhofer IOSB
jan-wilhelm.blume@iosb.fraunhofer.de

Philipp Hertweck
Fraunhofer IOSB
philipp.hertweck@iosb.fraunhofer.de

Tobias Hellmund
Fraunhofer IOSB
tobias.hellmund@iosb.fraunhofer.de

Jürgen Moßgraber
Fraunhofer IOSB
juergen.mossgraber@iosb.fraunhofer.de

INTRODUCTION

For emergency management agencies information retrieval is of particular importance since it is crucial for decision-making and the gain of situational awareness during a crisis. Many different data sources are available for the usage in the context of crisis management like for example weather forecasts, sensor data, historical context information or social media messages. By including all these different information sources vast amounts of data can be generated in short times. If not handled appropriately this can lead to informational overflow for human analysts. To prevent this an automated analysis, efficient visualization and appropriate filtering methods for the multi-modal data are required. A combined visualization of the different data sources will also help in this regard. It will improve the ability of analysts to get a better overview of the current situation as well as their ability to validate and verify single events.

In order not to be limited to some specific data sources a generic approach to a combined visualization of the data is desired. This will increase on the one hand the applicability of such a tool for different emergency management agencies and on the other hand its adaptability to changes of crisis management systems it is used in. A trade-off that often comes along with these generic approaches is that the data will be broken down to common features between the different data sources, which often results in a loss of information. This work presents an approach to the realization of a visualization tool that tries to accomplish both: the ability to include many different data sources as well as being configurable to each single data source to prevent a loss of information. The presented approach was developed in the frame of the beAWARE project (Karakostas et al. 2018), which aims for the creation of a holistic approach, that supports decision makers through all phases of a natural disaster related crisis, i.e. preparedness, response and recovery.

DESIGN CONSIDERATIONS

From the motivation stated in the introduction two requirements for the workbench can directly be derived. These are the ability to visualize combined data from different information sources and the ability to include these data sources in a generic way that allows for a high configurability. To reduce the threat of informational overflow a further requirement is a powerful filter system. Since time is a crucial constraint in crisis management, it is important that the visualization tool enables analysts to get the information they need in a relatively short time. The last requirement therefore was a quick access to the important functionalities.

For the visualization of data from different data sources one needs an attribute that is shared by the data and can therefore be used as a base for the visualization. Since a lot of the data used in crisis management will be location based a map was chosen for its visualization.

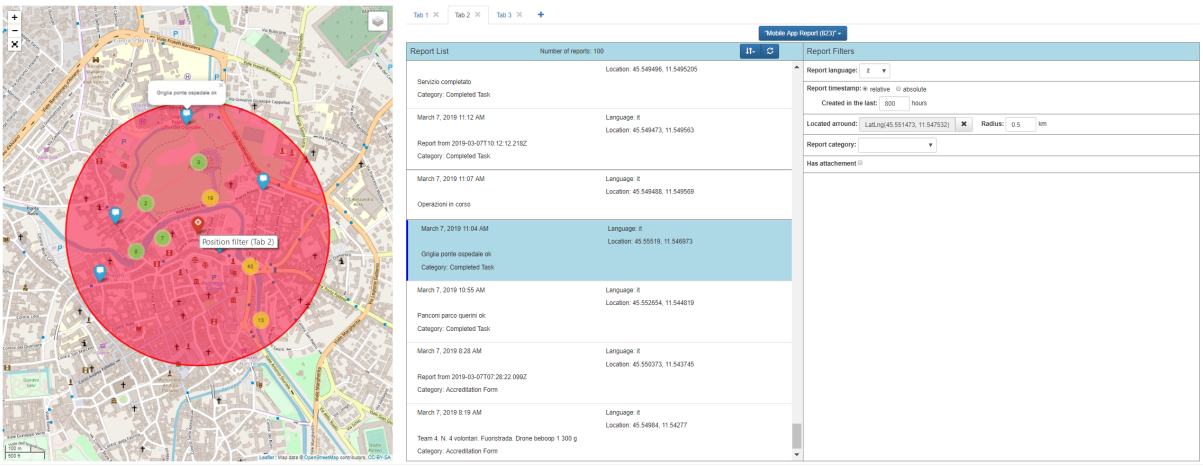


Figure 1. Overview of the Message workbench.

THE MESSAGE WORKBENCH

The message workbench was implemented as a web application, in order to be usable without a specific installation on multiple devices. Besides the map, a sortable list is used as a structured representation of the data. The graphical user interface of the tool consists therefore out of three main parts, which are the list, the filters and the map (see fig. 1). The list and the filters are placed inside tabs, which can be created and closed within the application. For each tab one data source needs to be selected. Due to the tab system a parallel analysis of different data sources is possible within the map.

In especially the filters and the list are implemented in a way, which allows for a high configurability to different data sources. On the one hand this allows analysts to filter and sort the list after each attribute available in the data. On the other hand, this enables an adaptable display of the data for each data source in the list.

The map will display all available origin locations of the messages in each tab that fits the chosen filters. The entries in the map and the lists are linked with each other so that a click on an entry in one of the two visualizations will highlight the entry in the other visualization as well. Further the map offers a second possibility to include data into the workbench by providing interfaces for the retrieval of data from several common spatial databases. For data that is integrated by one of these interfaces a map layer will be create, that can be toggled on and off. By this also non-message-based data can be integrated.

CONCLUSION AND FURTHER WORK

This work presents a design approach for a generic visualization workbench that is able to display data from different data sources in a common user interface. It includes a highly configurable filter engine, that shall allow analysts to gain knowledge from large amounts of data.

The workbench is still under developement. The inclusion of other visualization formats might be an interesting step in the future like for exp. a time-line as a time-based visualization of the data. Up to now a prototype of the workbench has been developed and was integrated into the crisis management system of the beAWARE project. A deeper evaluation of the system is currently ongoing.

ACKNOWLEDGMENTS

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation program under Grant No. 700475.

REFERENCES

Karakostas, A., Vrochidis, S., Kompatsiaris, I., Kantsepolsky, B., Moßgraber, J., Wanner, L., Mandler, B., Karppinen, A., Ferri, M., Vourvachis, I., et al. (Sept. 2018). "beAWARE: Enhancing Decision Support and Management Services in Extreme Weather Climate Events". In: *Proceedings of EnviroInfo 2018*.

Distributed Learning Automata-based Intelligence for Propagation-based Fake News Detection on Social Media During Crisis

Ahmed Abouzeid
University of Agder, Department of ICT
Center of Artificial Intelligence Research (CAIR)
Center of Integrated Emergency Management (CIEM)
ahmed.abouzeid@uia.no

Ole-Christoffer Granmo
University of Agder, Department of ICT
Center of Artificial Intelligence Research (CAIR)
Center of Integrated Emergency Management (CIEM)
ole.granmo@uia.no

Christian Webersik
University of Agder, Department of Global Development and Planning
Center of Integrated Emergency Management (CIEM)
christian.webersik@uia.no

Morten Goodwin
University of Agder, Department of ICT
Center of Artificial Intelligence Research (CAIR)
Center of Integrated Emergency Management (CIEM)
morten.goodwin@uia.no

INTRODUCTION

One of the recently revealed approaches to social media fake news detection is the propagation-based approach. the assumption is that information trustworthiness evidence could be unveiled by investigating different opinions and contradictions. In propagation-based methods, credibility networks are built to employ optimization techniques over different pieces of news giving the underlying point of view. Mining different viewpoints and reactions to news are referred to as stance detection tasks. Hence, stance detection attempts are required first to accomplish fake news detection. However, stance detection models are not either robust enough nor generalized on different datasets, since they are highly dependent on the specific training data feature space. That introduces the first challenge to propagation-based fake news detection. Another challenging and maybe avoided issue is the problem of biased opinions or accounts. That is because propagation-based techniques assume that trusted opinions would be a majority compared to fake ones. However, it is a bit naive hypothesis since biased and misleading viewpoints would be the majority in many cases. A biased piece of news could fall into three categories: *Biased purposely false*, *biased unintentionally false*, and *biased correct*. We consider only the first type as an obstacle to propagation-based fake news detection models since the other varieties do not have a considerable impact. The aim of our study is to develop a robust propagation-based fake news detection model that remains accurate regardless of the above-mentioned challenges. For that, we will simulate different use cases with biased and misleading stances. Our method does not require ground truth information for news credibility since we propose a non-sequential reinforcement learning instead of supervised learning. In the following sections, we will present the current solution and empirical results.

METHODOLOGY

We propose a distributed learning automata (DLA) method as a graph optimization framework to the problem of propagation-based fake news detection. DLA is a network of individual learning automata (LA). LA is a model of intelligent computation where learning is accomplished by exploring and its consequences, in an iterative and reinforcement manner. The objective is to decide the optimal action to select between all the possible actions. LA usually deals with randomness when there is no supervision of learning. Hence, LA learns by interacting with an

environment, sometimes is called a teacher. The environment sends regular feedbacks for when the LA explores a particular action. The LA refines its action selection in future explorations with regard to the environment recent response. Our DLA is constructed on top of a social graph where social media messages and their provided stance information are representing the graph vertices and edges weights respectively. Each automaton will be associated with a node in the graph. At each step in time, a randomly generated set of automata pairs is formed. In each pair, one automaton is active and the other is passive. For each pair, the active automaton is the one that will explore a possible action and the other one is considered the environment of the first automaton and will remain passive until next round. The DLA network is uninformed where all automata share the same structure with two possible actions: *Fake* and *Trust*. Each underlying node in the DLA is initialized with a weight that should guide its associated automaton to approximate its finally chosen action probability for the associated message. The initial weight is a probabilistic value which estimates a percentage of the non-biased contradicted opinions with the message. Then, and randomly, each pair elements interact together, and each active automaton tries to estimate its fake/ trust probability distribution vector according to the interaction feedback while nodes weights are adjusted as well. The below formula demonstrates how LA actions probabilities would change.

$$\pi_{[fake,\ t+1]} = \begin{cases} \pi_{[fake,\ t]} + \boldsymbol{\Delta} & penalize\ fake = \mathbf{0} \\ \pi_{[fake,\ t]} - \boldsymbol{\Delta}, & penalize\ fake = \mathbf{1} \end{cases}$$

$$\pi_{[trust,\ t+1]} = 1 - \pi_{[fake,\ t+1]}$$

$$\text{Where } \boldsymbol{\pi}_t = \begin{bmatrix} \pi_{[fake,\ t]} \\ \mathbf{1} - \pi_{[fake,\ t]} \end{bmatrix} \text{ or } \boldsymbol{\pi}_t = \begin{bmatrix} \pi_{[fake,\ t]} \\ \pi_{[trust,\ t]} \end{bmatrix}$$

and **Δ** is the amount to increase the probability of an action when rewarded or decrease it when penalized after evaluating some conditions at time step **t**. Then, the automaton probability vector $\boldsymbol{\pi}$ is updated. Our experiments used both artificial data to simulate different scenarios and real-world data collected by the PHEME project [1]. The latter was post-processed by us in order to structure the stances and credibility ground truth in an easy format. The PHEME dataset was originally collected and annotated from tweets talking about Charlie Hebdo shooting. In the following section, we demonstrate our empirical results on both types of data.

RESULTS

According to the below empirical results, it was inferred how a high biased data, providing less stance information, and difference in the percentage of fake samples would affect the performance of DLA. However, our proposed DLA still perform above average in some of these challenging situations.

Dataset	Number of Samples	Fake Perc	Stance Perc	Biased Perc	Accuracy	Precision	Recall	F1 Score	Convergence Time Avg (Iterations)
Exp1	**100**	**.50**	**.38**	**.34**	**.73**	**.64**	**1**	**.78**	**2500**
Exp2	**100**	**.50**	**.64**	**.40**	**.75**	**.66**	**1**	**.80**	**2500**
Exp3	**100**	**.50**	**.34**	**.64**	**.27**	**.36**	**.51**	**.42**	**2500**
Exp4	**100**	**.50**	**.67**	**.45**	**.73**	**.65**	**.98**	**.78**	**2500**
Exp5	**100**	**.10**	**.62**	**.08**	**.35**	**.13**	**1**	**.24**	**2500**
Exp6	**100**	**.90**	**.47**	**.87**	**.65**	**.87**	**.72**	**.79**	**2500**
Charlie Hebdo	**213**	**.34**	**.09**	**.35**	**.54**	**.52**	**.50**	**.51**	**2500**

CONCLUSIONS AND FURTHER WORK

We proposed an under-development method to propagation-based fake news detection which is more robust in biased scenarios. The empirical results show how the DLA performance varied with different percentages of existed fake samples. Moreover, the percentages of biased and provided stances affected how DLA performed. Further work would be the investigation of these obstacles with a complete formalization of both problem and solution, we also suggest developing a different LA structure and compare it with the current LA structure.

REFERENCIES

[1] HTTPS://WWW.PHEME.EU/

Analysis of Tweets with Rescue Request Hashtags in The 2018 Japan Floods

Shuji Nishikawa
Tokai University
s.nishikawa@utsuken.net

Osamu Uchida
Tokai University
o-uchida@tokai.ac.jp

Keisuke Utsu
Tokai University
utsu@utsuken.net

INTRODUCTION

Large-scale natural disasters are a frequent occurrence in Japan. During and after the disasters, numerous messages (i.e., tweets) related to the disaster are posted on Twitter. At the times of recent disasters, such as the 2017 Northern Kyushu Floods in Japan and the 2018 Japan Floods (the July 2018 Heavy Rain Disaster in Japan), victims who needed to be rescued used the hashtag #救助 (meaning #Rescue) in the tweets they posted to request a rescue. Usually, if a victim needs to be rescued, an emergency phone call with a rescue request can be made (to the numbers 110 or 119 in Japanese phone networks). In the 2018 Japan Floods, a record-breaking heavy rain poured down in western Japan in July 2018, killing 222 people and causing severe damage. Media reports have noted that the fire department could not receive and respond to all of the rescue request calls because of their vast number. However, many victims did post tweets requesting a rescue on Twitter as an alternative to making emergency calls. Because only a few studies have investigated the effectiveness of such hashtags, an investigation into the circumstances of the posted tweets with rescue request hashtags needs to be conducted to enable better rescue and supporting activities. In this study, we collect and analyze tweets with rescue request hashtags that were posted during the 2018 Japan Floods.

ANALYSIS OF TWEETS WITH RESCUE REQUEST HASHTAGS

The tweets posted during the 2018 Japan Floods that included the word 救助 (rescue) were collected using the Twitter Standard search application programing interface (API) provided by Twitter Developers. We investigated the tweets that were posted between 12:00 on July 6 and 23:59 on July 8, focusing on the 224,976 tweets with a rescue request hashtag. The rescue request hashtags we considered in this study include #救助 (meaning #Rescue) and combinations of the type #救助 xxxx (a combination of #救助 and another word), the number of original tweets (OTs) was 3,395 and the number of reposted tweets, or retweets, was 221,581. We classified the OTs into one of the categories listed below. If the tweets included images, videos, or hyperlinks that were still available, we referred to them to improve the classification.

- R1: Tweets that are requesting the rescue of a contributor, an individual, or a group. Tweets in this category include a detailed address (such as the house number, street number, and name of the location) or a description of a landmark at the location where the rescue is requested. These tweets should use the hashtag #救助, as instructed by the @TwitterLifeline account (@TwitterLifeline, 2018).
- R2: Tweets that are requesting a rescue, but which do not satisfy the conditions for category R1, e.g., detailed information on the location in which the rescue is requested.
- X: Tweets that describe the process of posting and/or sharing rescue request posts or the use of hashtags on Twitter or another social networking service (SNS).
- Y: Tweets not classified as an R1-X tweet, but talking about the disaster.
- Z: Tweets not classified as an R1-Y tweet.

Figure 1 shows the distribution of the OTs in the five defined tweet categories for 3,395 tweets. Even though the

number of tweets with rescue requests was small during the 2017 Northern Kyushu Floods (Sato and Imamura, 2018; Nishikawa et al., 2018), the number of such tweets during the 2018 Japan Floods experienced a marked increase. One reason for this may be the larger scale of the disaster than that which occurred in 2017. Conversely, 74.6% of the tweets (2,534 of 3,395) did not contain a rescue request and was classified into the categories X, Y, or Z. This behavior is similar to that observed in the case of the 2017 Northern Kyushu Floods (Sato and Imamura, 2018; Nishikawa et al., 2018).

Figure 2 shows a histogram of the number of posted OTs per hour. The total number of tweets began to increase from around 4:00 on July 7. The number of tweets began to increase about five hours after the special heavy rain warning was issued at 22:40 on July 6 at Kurashiki City in the Okayama Prefecture, where the most serious damage occurred. In Japan, such a special warning is issued by the Meteorological Agency when a weather phenomenon is observed that far exceeds the criteria for a general weather warning. The total number of tweets approached the first peak around 9:00, after which it slightly decreased, only to reach the second, higher peak around 13:00. The number of posted OTs then decreased, reaching comparatively small values after 23:00. The number of tweets may have decreased after 23:00 because of the late hours of the night or because the special heavy rain warning was called off (at 6:00 on July 8). On the next day, the number of OTs per hour began to increase again, up to the value of tens of tweets per hour.

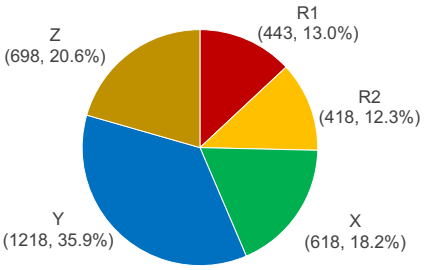


Figure 1. Distribution of tweet categories for 3,395 original tweets (OTs).

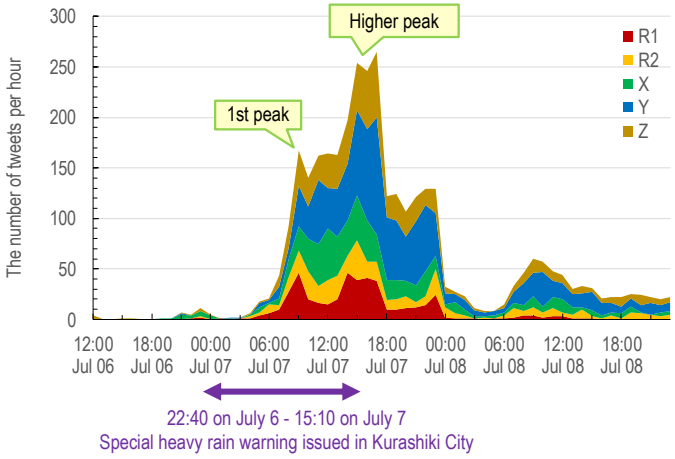


Figure 2. Histogram showing the number of original tweets (OTs) (stacked graph).

CONCLUSIONS

We analyzed the contents and trends of the tweets with rescue request hashtags that were posted during the 2018 Japan Floods. To efficiently and quickly utilize the rescue request tweets and respond with actual rescue activities, it would be useful to have a system, which can display the rescue requests on an online map based on the provided location information. We plan on developing this system in the future.

ACKNOWLEDGMENTS

This study has been supported by Grant-in-Aid for Scientific Research (KAKENHI) 17K12989, Japan Society for the Promotion of Science (JSPS).

REFERENCES

Nishikawa, S., Tanaka, N., Utsu, K., Uchida, O. (2018) Time Trend Analysis of "#Rescue" Tweets During and After the 2017 Northern Kyushu Heavy Rain Disaster, 5th International Conference on Information and Communication Technologies for Disaster Management (ICT-DM 2018)

Sato, S., Imamura F. (2018) An Analysis of Tweet Data Tagged with "#Rescue" in the 2017 North Kyushu Heavy Rain Disaster, *J. JSNDS, 37-1*, 93-102 (in Japanese).

@TwitterLifeline (2018) twitter, https://twitter.com/TwitterLifeline/status/1016519147738419201

Social Media in Disaster Management: Exploring the Information Exchange Behavior in the Underserved Communities

Thiagarajan Ramakrishnan
Prairie View A&M University
Ram@pvamu.edu

Louis Ngamassi
Prairie View A&M University
longamassi@pvamu.edu

Shahedur Rahman
Prairie View A&M University
shrahman@pvamu.edu

INTRODUCTION

The purpose of this paper is to examine the role of social media in the underserved communities to manage disasters. We draw on the *Uses and Gratification Theory, Situational Theory of Problem Solving,* and the research on *Communication Behavior* to develop a comprehensive model that will help identify people's behavior in the underserved communities when faced with an imminent disaster and their choice of social media for communication purpose during disaster. Our conceptual model and the propositions are given below. This paper is still work in progress. In the methodology section, we provide the method used to develop the conceptual model and the propositions. In the results section, we provide our conceptual model and the propositions. This paper finally concludes by proposing the further work that needs to be undertaken for completing this project.

METHODOLOGY

In order to understand the use of social media in disaster management, we conduct an extant literature review pertaining to social media and disaster management. We then identify the theories that can help us answer our question regarding the use of social media. Based on the theories, we develop our research model and state our propositions.

Prior studies have indicated that there is an increase in the use of social media for managing disasters. Social media enables open online discussions through interactions and conversations (Ngamassi et al., 2016). They facilitate the formation of new communities and have the potential to re-energize old ones (Omilion-Hodges and McClain, 2016). They also have the ability to establish widespread communication and flexibility to the changing needs of disaster responders and at the same time reinforcing information flow (Ngamassi et al., 2016). Despite social media being a powerful communication tool with great potential to aid in disaster management, past studies have indicated that it has not been used effectively in managing disasters (Ngamassi et al., 2016). This is specifically true in case of underserved communities (Nakahara and Ichikawa, 2013). In this study, we examine Uses and Gratification (U&G) theory, Situational Theory of Problem Solving (STOPS), and research on Communicative Actions in Problem Solving (CAPS) to understand how social media can be used effectively in the underserved communities for disaster management.

RESULTS

As mentioned in the previous section, we use U&G theory, STOPS, and literature on CAPS to develop our research model. We then state our propositions based on our research model.

Figure 1 shows our research model.

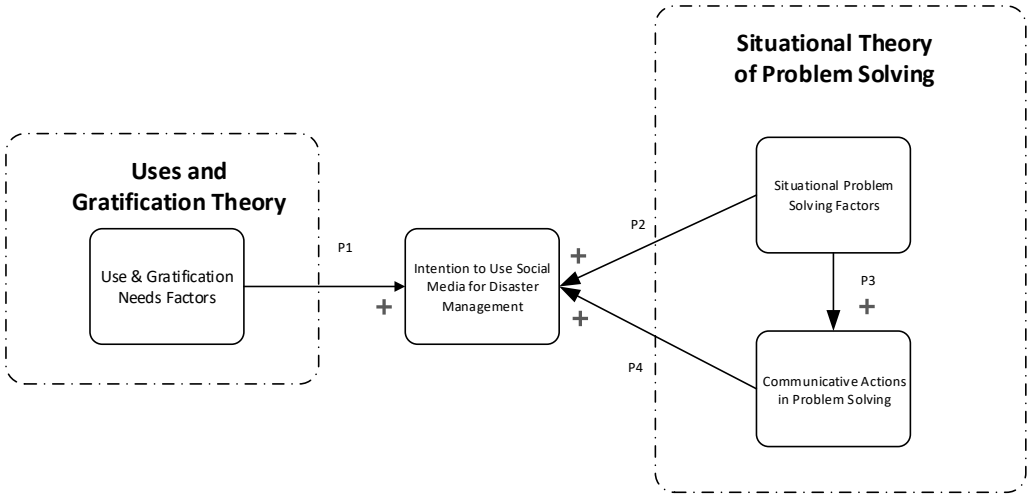


Figure 1: Research Model

Based on the above model, we make the following four propositions:

P1: There exists a positive relationship between social media use in gratifying needs factors and the intention to use social media for disaster management

P2: There exists a positive relationship between individuals' situational problem solving factors regarding disaster and the intention to use social media for disaster management

P3: There exists a positive relationship between individuals' situational problem solving factors regarding disaster and the communicative actions of problem solving for managing disasters

P4: There exists a positive relationship between communicative actions of problem solving and the intention to use social media for disaster management

CONCLUSIONS AND FURTHER WORK

In conclusion, this study focuses on providing a conceptual model to understand the use of social media for disaster management. Four propositions provide a theoretical foundation for future empirical studies. This study also contributes to the literature focused on the use of social media for managing disasters and has practical implications as well.

Further work is required in operationalizing these constructs and collecting the data. Once data is collected, the next step involves testing the data for reliability and validity issues. The final step is to test the model to see how well the data fits our model.

ACKNOWLEDGMENTS

This article was written based upon work supported by the U.S. Department of Homeland Security under Grant Award Number, 2017-ST-062-000005.

We also wish to thank Dr. Jeong-Nam Kim from Debiasing and Lay Informatics (DaLI) Lab for sharing his instrument on STOPS and for going over our model and giving us feedback regarding our model.

REFERENCES

Nakahara, S. and Ichikawa, M. (2013). Mortality in the 2011 Tsunami in Japan, *Journal of Epidemiology*, 23, 1, 70-73.

Ngamassi. L., Ramakrishnan, T. and Rahman, S. (2016). Examining the Role of Social Media in Disaster Management from and Attribution Theory Perspective, *Proceedings of the Thirteenth International Conference on Information Systems for Crisis Response and Management*, Rio de Janeiro, Brazil.

Omilion-Hodges, L.M. and McClain, K.L. (2016). University Use of Social Media and the Crisis Lifecycle: Organizational Messages, First Information Responders' Reactions, Reframed Messages and Dissemination Patterns, *Computers in Human Behavior,* 54, 630-638.

AIOSAT - Autonomous Indoor & Outdoor Safety Tracking System

Iñigo Adin
CEIT
iadin@ceit.es

Bart Scheers
RMA
bart.scheers@rma.ac.be

Jose Manuel Sanchez
INTEGRASYS
jose.sanchez@integrasys-sa.com

Javier Ferreira
SAXION
j.ferreiragonzalez@saxion.nl

Berend Jan van der Zwag
INERTIA
berendjan@inertia-technology.com

Didier de Wulf
Hulpverleningszone Centrum
didier.dewulf@bwzc.be

Ymko Attema
Twente Safety Campus
y.attema@brandweertwente.nl

INTRODUCTION

The Europe population experiences yearly about 2 million to 2.5 million fires with 20 to 25 thousand deaths and 250 to 500 thousand reported injuries [1]. Moreover, EUFireAcademy states European countries suffered 558 fatalities per million inhabitants due to fire hazards during the year 2010.

Even though satellite-based positioning technology allows rescue workers to already operate efficiently, GPS availability, reliability, and accuracy are often poor during fire operations, for example due to thick smoke, dense forests, rough terrain and inside buildings. In this context, the objective of AIOSAT (Autonomous Indoor & Outdoor Safety Tracking System) [2] is to progress beyond the state of the art by defining the AIOSAT concept that aims to overcome aforementioned limitations of GNSS usage in rescue interventions. For this purpose, GNSS positions are enhanced with EGNOS and fused with position information inferred from IMU and RF.

METHODOLOGY

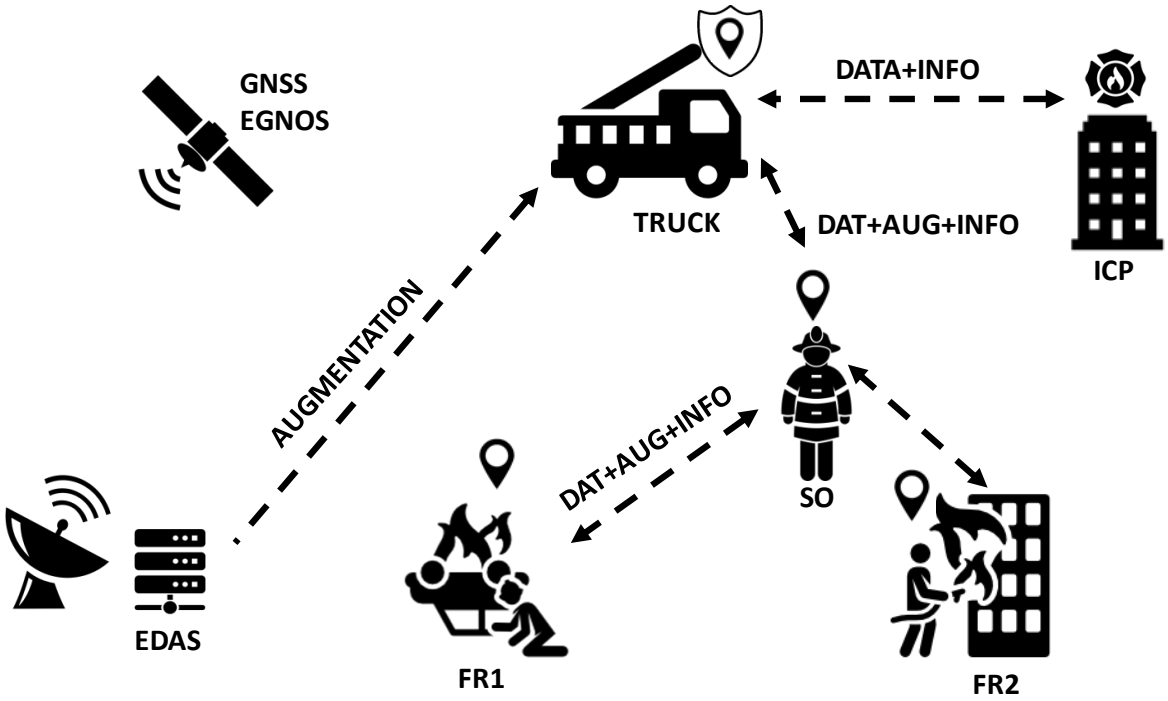
The main paths to the goal will be to define 1) the end-user requirements for the AIOSAT system, 2) the Advanced Positioning Subsystem 3) the Communications Subsystem 4) the tracking and alerting (TA) application and, 5) build an integrated prototype system validated during field tests.

The overarching objective of AIOSAT system is to advance beyond the state of the art in tracking rescue workers by creating a high availability and high integrity team positioning and tracking system. On the system level approach, this goal is achieved by fusing the GNSS with RTK approach [3], EGNOS, pedestrian dead reckoning (PDR) and ultra-wide band (UWB) ranging information, possibly augmented with map data. The system should be able to work both inside buildings and rural areas, which are the test cases defined by the final users involved in the consortium and the advisory board panel of the project.

The AIOSAT system will allow the team/brigade commander to track the location, including a confidence margin on the location, answering a necessity of the emergency services, and therefore the team commander will handle the information required for the success of the operation and to avoid any fatalities.

RESULTS

The AIOSAT system architecture is based on the components shown in the following figure:



CONCLUSIONS AND FURTHER WORK

The AIOSAT project aims at providing high-reliability location information during rescue operations for a safer operation. Its design focuses on modularity and ensuring data availability by integrating multiple sensors such as GNSS, IMU and UWB ranging subsystem, from which information, a fusing algorithm obtains the localization data. In the coming months, the partners will work towards the integration of all the sub-components for subsystem validation and full system validation in the 3 scenarios defined with the international end users.

ACKNOWLEDGMENTS

Results incorporated in this project received funding from the European GNSS Agency under the European Union's Horizon 2020 research and innovation programme under grant agreement No 776425.

REFERENCES

[1] N.N. Brushlinsky, M. Arhens, S.V. Sokolov, P. Wagner, *World Fire Statistics* v.28 2018

[2] Autonomous Indoor/Outdoor Safety Tracking System *(AIOSAT) webpage*, http://www.aiosat.eu/

[3] William J. Kellar, Miles P. Moody, *Transmission of RTK Corrections and Measurements using Optimal Coding,* Journal of Global Positioning Systems 2006

Towards a privacy aware information system for emergency response

Alba Morales
The Open University
alba.morales-tirado@open.ac.uk

Enrico Daga
The Open University
enrico.daga@open.ac.uk

Enrico Motta
The Open University
enrico.motta@open.ac.uk

INTRODUCTION

Intelligent Systems in Smart Cities capture and exchange a large variety of information, for example, environmental data, localisation, biometric and personal data, health records, among others, in order to improve the quality of services.

On one hand, such systems could represent an important, lifesaving resource for public services aimed at addressing emergency situations (e.g. firefighters, police), by providing access to a large amount of diverse information. On the other hand, they are also a threat with respect to data protection and privacy when disclosing all sort of personal and sensitive information.

Since not all the information available can be used or helpful for handling the emergency we have the challenge of ensuring that the least possible amount of sensitive information is exchanged, therefore reducing the risk of unwanted disclosure and misuse. Thus, being aware and include a privacy-by-design approach when managing personal and sensitive data is essential in the context of emergency systems.

This work aims to analyse the privacy issues that Intelligent Systems face when sharing information with public services to attend emergency situations. By characterising these issues, we aim of informing the knowledge requirements for designing an Intelligent System that only allows valuable and helpful information to be exchanged, minimising personal and sensitive data disclosure.

BACKGROUND AND RELATED WORK

Smart Cities have put in place a set of different Intelligent Systems (IS) that are constantly monitoring, sharing and storing a heterogeneous range of information with the aim to help at improving and planning public services (e.g. transportation, energy and water consumption, environment, education, health, social), for the benefit of their citizens (van Zoonen, 2016). It is clear that the information collected by such systems is diverse and ranges from public data to private and sensitive data, according to its objective (Wang et al., 2015). For instance, systems that assist daily activities for elderly people by monitoring biometric data of the patient (Aleksandar Rodić et al. 2016), or applications that aim to help citizens with respiratory problems by monitoring air pollution and its location to suggest safe routes (Mateo Pla et al. 2016), video surveillance systems capturing and recording images/videos of citizens (Dufaux and Ebrahimi 2005), are some examples of IS that manage sensitive information. In addition, the information generated by Intelligent Systems is becoming essential for the development and function of Emergency Systems which rely on the detailed information given by the Smart Cities to improve citizen's safety and attend emergency situations (Garcia et al. 2018; Palmieri et al. 2016; Patsakis et al. 2015). However, data privacy breaches appear in the context of Smart Cities Systems, as mention before, mainly because these systems gather an exceptional volume of information that can compromise citizen's privacy (Martinez-Balleste et al. 2013). Therefore, in the context of emergency systems, providing access to this information represents an important resource (Chehade et al., 2018), but in the same way, this massive disclosure of information constitutes a threat with respect to data protection and privacy when this information contains personal and sensitive data.

APPROACH

As not all information available is important or helpful for emergency services, we have the challenge to assure the minimal possible amount of personal and sensitive information is shared. Thus, protecting people's privacy and preventing disclosure and misuse (Ding et al. 2016). However, since this information is heterogeneous and comes from many different sources, the need for one intelligent layer that can govern this diversity is imperative. In this context, semantic technologies can play a crucial role (d'Aquin et al. 2015), for example, in governing the multiplicity of data, processes, and policies involved (Daga et al. 2015, 2016). Our approach consists of developing an ontology for discriminating between sensitive and not sensitive information. Giving a person in danger the ontology should be able to automatically evaluate what is the information necessary to help this person and, at the same time, assuring that the minimal and sufficient information is disclosed, hence avoiding data privacy issues and providing emergency services/systems with helpful information.

RESULTS

To illustrate how privacy issues arise when Intelligent Systems share information with emergency systems, we selected a use case scenario (Srinivasan et al. 2016) to exemplify the case of a fire event. Next, with the purpose to learn how privacy issues are handled in a given emergency event (a fire event), we conducted an extensive survey in a large organisation: The Open University. The University and its Health & Safety Department provide a great amount and well structure documentation that is not limited only to fire events (for instance covers topics as First Aid, Accident, Incident and near-miss information and Display Screen Equipment (DSE)). Furthermore, it complies with Statutory Instruments and British Standards. Therefore, it constitutes a good, paradigmatic and concrete case study. At first, we analysed the relevant information and the procedures in case of fire events stated in the University's documentation, then we familiarised ourselves with the organisation's fire safety guidelines and regulations. Next, we identified the data privacy issues to later extract the requirements that a privacy-aware Intelligent System has to consider. Finally, we analysed the findings in the light of an Intelligent System solution. The list of competency questions in Table 1 is our first output of this work in progress poster that we want to present and discuss with the audience.

Number	Competency Questions
CQ1.	Is the IS able to differentiate between public and private information?
CQ2.	What information can be considered as public, private or sensitive information?
CQ3.	Is the IS able to understand the impact of sharing sensitive and non-sensitive information?
CQ4.	Is it possible for the IS to identify trusted services or systems?
CQ5.	Is the intelligent system able to discriminate what information could be necessary in order to attend the emergency?
CQ6.	What is the level of detail of information required to attend a specific emergency event?
CQ7.	Is the intelligent system able to discriminate what information could be sufficient in order to attend the emergency?
CQ8.	Is the intelligent system capable of assuring the minimality of the data shared in order to attend the emergency?
CQ9.	How to preserve data security of information stored after it was used by an emergency system?

Table 1 Competency questions

CONCLUSIONS AND FURTHER WORK

Undoubtedly, data privacy concerns are present in Intelligent Systems that collect, store and share any type of information. In emergency situations, the IS deal with a large amount of personal information, that once shared with emergency systems might derive in privacy disclosure. This work in progress poster aims at presenting the initial results towards a proposed approach of building an ontology capable of (i) discriminating between sensitive and not sensitive information, (ii) disclosing as minimal information as possible and equally important (iii) serving necessary and sufficient data to help the emergency.

REFERENCES

Aleksandar Rodić, Milica Vujović, Ilija Stevanović, and Miloš Jovanović. (2016). "Development of Human-Centered Social Robot with Embedded Personality for Elderly Care." *New Trends in Medical and Service Robots*, Mechanisms and Machine Science.

Chehade, S., Matta, N., Pothin, J.-B., and Cogranne, R. (2018). "Data Interpretation Support in Rescue Operations: Application for French Firefighters." *2018 IEEE/ACS 15th International Conference on Computer Systems and Applications (AICCSA)*, IEEE, Aqaba, Jordan, 1–6.

Daga, E., d'Aquin, M., Gangemi, A., and Motta, E. (2015). "Propagation of Policies in Rich Data Flows." *Proceedings of the Knowledge Capture Conference on ZZZ - K-CAP 2015*, ACM Press, Palisades, NY, USA, 1–8.

Daga, E., d'Aquin, M., Adamou, A., and Motta, E. (2016). "Addressing exploitability of Smart City data." *2016 IEEE International Smart Cities Conference (ISC2)*, IEEE, Trento, Italy, 1–6.

Ding, D., Conti, M., and Solanas, A. (2016). "A smart health application and its related privacy issues." *2016 Smart City Security and Privacy Workshop (SCSP-W)*, IEEE, Vienna, Austria, 1–5.

Dufaux, F., and Ebrahimi, T. (2005). "Smart video surveillance system preserving privacy." A. Said and J. G. Apostolopoulos, eds., San Jose, CA, 54.

d'Aquin, Mathieu; Adamou, Alessandro; Daga, Enrico; Liu, Shuangyan; Thomas, Keerthi and Motta, Enrico (2014). Dealing with diversity in a smart-city datahub. In: *Proceedings of the Fifth Workshop on Semantics for Smarter Cities*, CEUR Workshop Proceedings, CEUR-WS.org, pp. 68–82.

Garcia, L., Parra, L., Taha, M., and Lloret, J. (2018). "System for Detection of Emergency Situations in Smart City Environments Employing Smartphones." *2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, IEEE, Bangalore, 266–272.

Martinez-Balleste, A., Perez-martinez, P., and Solanas, A. (2013). "The pursuit of citizens' privacy: a privacy-aware smart city is possible." *IEEE Communications Magazine*, 51(6), 136–141.

Mateo Pla, M. A., Lemus-Zúñiga, L. G., Montañana, J.-M., Pons, J., and Garza, A. A. (2016). "A Review of Mobile Apps for Improving Quality of Life of Asthmatic and People with Allergies." *Innovation in Medicine and Healthcare 2015*, Y.-W. Chen, C. Torro, S. Tanaka, R. J. Howlett, and L. C. Jain, eds., Springer International Publishing, Cham, 51–64.

Palmieri, F., Ficco, M., Pardi, S., and Castiglione, A. (2016). "A cloud-based architecture for emergency management and first responders localization in smart city environments." *Computers & Electrical Engineering*, 56, 810–830.

Patsakis, C., Papageorgiou, A., Falcone, F., and Solanas, A. (2015). "s-health as a driver towards better emergency response systems in urban environments." *2015 IEEE International Symposium on Medical Measurements and Applications (MeMeA) Proceedings*, IEEE, Torino, Italy, 214–218.

Srinivasan, R., Mohan, A., and Srinivasan, P. (2016). "Privacy conscious architecture for improving emergency response in smart cities." *2016 Smart City Security and Privacy Workshop (SCSP-W)*, IEEE, Vienna, Austria, 1–5.

van Zoonen, L. (2016). "Privacy concerns in smart cities." *Government Information Quarterly*, 33(3), 472–480.

Wang, P., Ali, A., and Kelly, W. (2015). "Data security and threat modeling for smart city infrastructure." 2015 International Conference on Cyber Security of Smart Cities, Industrial Control System and Communications (SSIC), IEEE, Shanghai, China, 1–6

Mission Track: Plans into Actions

Víctor A. Bañuls
Universidad Pablo de Olavide
vabansil@upo.es

Jaime E. del Palacio
Mission Track
jpp@missiontrack.es

Eduardo del Palacio
Mission Track
epl@missiontrack.es

Fernando Tejedor
Mission Track
ftp@missiontrack.es

INTRODUCTION

Organizations are facing threats which can cause great damage and jeopardize its viability. Hence, they must be prepared beforehand to respond effectively by elaborating action plans to limit damage propagation. Nevertheless, this emergency response plans are presented in different formats, such as documents or data sheets that show little effectiveness at an emergency situation by making it impossible to respond in an effective manner.

For that reason, they should be prepared to respond to their materialization, stopping further damage through:

- Security plans.
- Self-protection plans.
- Crisis-management plans.
- Site emergency plans.
- Environmental emergency plans.
- Business continuity plans.

Plans are usually displayed in a little functioning format in a real emergency situation, making an effective response more difficult:

- Alert: misinformation on what to communicate, to whom, and how.
- Classification: lack of information on the type of the event, magnitude, and exact position. f
- Activation: difficulty to identify and locate team members of intervention in every step, or to its substitutes.
- Response: difficulty to locate the suitable action sheet in each case for every team.
- Coordination: difficulty to identify the location of each team at any time, and to follow the degree of advancement of actions.

Mission Track is a system aimed at helping operational deployment, monitoring and controlling mission critical systems. Mission Track is a very suitable tool to use it for planning, developing and training Emergency teams.

METHODOLOGY

During the Demo Session we will present several functions of Mission Track, as well complete interactive emergency scenario with different roles (Figure 1):

- The system provides the notification of an incident detected by any observer through an application (app) by reporting the magnitude of the incident, the number of possible victims and its geolocation.
- The coordinator, who receives a notification of the alert in the app, takes the decision to activate

the planned response program based on the information and location of the incident.

- In case of activation, the system sends an alert to all members of the emergency response teams, who must confirm their availability.
- The system sends to each member of the response team the instructions of the planned response program and the location of the incident.
- The system allows the emergency control to monitor the location of the intervention teams' members, as well as tracking the progress of the response.
- The head of the intervention team informs the emergency control of each of the steps completed in the action plan through the app.
- The system automatically records not only the progress time of each intervention status (arrival at the location, start, control and end of the intervention), but also each step of the action plan by facilitating the subsequent evaluation of the emergency.

Figure 1: Mission Track

With this demo we will show how Mission Track:

- Improves the identification and notification of incidents
- Improves training and emergency training
- Improves the deployment and control of response plans and equipment

REFERENCES

Aedo, I., Díaz, P., Bañuls, V.A., Canos, J. and Hiltz, S.R. Information Technologies for the planning and training for Civil Protection, ISCRAM 2011, Lisbon (Portugal).

Bañuls, V.A., Turoff, M., Hiltz, S.R., Plotnick, L., Del la Huerga, M. Scenario Based Approach for Risks Analysis in Critical Infrastructures, ISCRAM15, Kristiansand (Noruega), mayo de 2015

Turof, M., Hiltz, S.R., Bañuls, V. and Van den Eede, G, Multiple Perspectives on Planning for Emergencies: An Introduction to the Special Issue on Planning and Foresight for Emergency Management, Technological Forecasting and Social Change, 80(9) pp. 1647–1656.

Turoff, M., Bañuls, V., Hiltz, S.R. and Plotnick, L. A Development of a Dynamic Scenario Model for the Interaction of Critical Infrastructures, ISCRAM 2014, State College (US), 2014.

Turoff, M., Chumer, M., Van de Walle, B., Yao, X., The Design of a Dynamic Emergency Response Management Information System (DERMIS), Annual Review of Communications, Volume 58, March 2006, Chosen as one of the best engineering communication papers of the year 2004 by the International Engineering Consortium, pp. 637-661.

Turoff, M., Hiltz, S. R., White, C., Plotnick, L., Hendela, A., Xiang, Y., The Past as the Future of Emergency Preparedness and Management, Journal of Information Systems for Crisis Response and Management, 1(1), 12-28, January-March 2009.

Organized by

Sponsored by