Sensor Requirements for Logistics Analysis of Emergency Incident Sites

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ABSTRACT

Using sensors to collect data at emergency incident sites can facilitate analysis of the logistic operations. This can be used to improve planning and preparedness for new operations. Furthermore, real-time information from the sensors can serve as operational decision support. In this work in progress, we investigate the requirements on the sensors, and on the sensor data, to facilitate such an analysis. Through observations of exercises, the potential of using sensors for data collection is explored, and the requirements are considered. The results show that the potential benefits are significant, especially for tracking patients, and understanding the interaction between the response actors. However, the sensors need to be quite advanced in order to capture the necessary data.

Keywords

Sensors, Emergency Response Planning, Tracking, Team Interaction.

INTRODUCTION

In case of an emergency incident, time is crucial and relevant information is at the same time often scarce. To make decisions in a fast and precise manner is therefore vital for a successful operation. The aim of this work is to investigate the feasibility and the potential of using sensor data in order to improve such decision making. Furthermore, the requirements on the data and on the sensors are considered.

The main idea is to use sensors to collect data at emergency incident sites and then analyze the logistic operations in order to identify improvement opportunities. The visionary goal is to be able to contribute to an increased efficiency among the various actors participating in the rescue work, through various logistical improvements. Furthermore, as decisions are based on the available information, better information can facilitate better decisions. We foresee that sensors will be able to provide real-time information and hence provide a better situational awareness. This then constitutes a good base for decisions on allocating resources and assignment of tasks, and can also be used as input for automatic decision support, based on artificial intelligence or optimization algorithms.

However, in order to achieve this goal, it is first necessary to analyze if, and further how, logistics at an incident site can be improved by quantitative modelling and data obtained through sensors. Thus, the following research questions have to be answered:

- What are the potential benefits of using sensors to collect data at an incident site?
- What are the requirements on the design of such sensors?

To achieve this, a literature study and the observations of several emergency incident exercises were performed. The collected data was divided into use cases, illustrating when it would be beneficial to have access to sensor data, and requirements, stating which data that would be useful and what is required from a sensor to capture and deliver this data. In the next section, the frame of reference for the study is outlined, and a small selection of previous work is described. Then the method is detailed, followed by the results, a discussion and finally the conclusions.

FRAME OF REFERENCE

In case of an emergency, the logistics of the rescue operations are crucial in order to achieve good results. Resources and patients must be transported and managed as they are a part of a supply chain in a humanitarian setting (e.g. van Wassenhove, 2006). As such, the field of humanitarian logistics (e.g. Kovács and Spens, 2009) has become important during the past decade. Regardless of the size of the event, there is always a possibility to optimize the resource utilization, and thereby contribute to the saving of lives and minimization of damages. As such, (Caunhye et al. 2012) put forward a review of optimization in emergency logistics. Different disasters and events have different logistical implications, depending on e.g. the urgency, duration, climate, etc. (L'Hermitte et al., 2014). However, good performance is always directly related to the ability of planning the resources (e.g. Rauner et al., 2012; Jagtenberg et al., 2015).

There exists previous work where the possibility to utilize sensors, and sensor networks, to analyze and improve emergency response and disaster management is investigated. For example, patient tracking supported by RFID technology has shown promising results in exercise settings (Jokela et al., 2008, 2012). Lorincz et al. (2004) describe a software architecture called CodeBlue, which can facilitate the monitoring and tracking of patients and first responders. They outline some technical requirements, including discovery and naming (it must be possible to identify all sensors), robust routing (ad hoc routing may be necessary to reach all devices), prioritization of critical data (due to limited bandwidth, a prioritization scheme might be necessary), security (the transmitted data need to be encrypted and secure), and tracking device locations (a mix of techniques should be used to get reliable location data for vehicles, patients and responders). Chandra-Sekaran et al. (2009) developed a sensor network for patient tracking during a crisis. They state that it should be able to handle both outdoor and indoor environments, use a minimal infrastructure, track 30-500 patients moving with varying speeds with a location accuracy of 5 to 10 meters, be scalable and robust and have a low computation and communication overhead. Indoor tracking is a well-known problem, where GPS signals can be blocked and the accuracy is reduced. To overcome this, Zhang et al. (2013) present a localization and monitoring system based on inertial sensors, which can be used by emergency responders.

Xu et al. (2013) focus on Internet of Things (IoT) architecture for logistics management. They use emergency response as a case study, and describe a set of general strategic benefits that IoT may give. These are "1. better resource allocation, 2. cooperation between various organizations, 3. faster and accurate situation awareness, 4. complete visibility of disaster development and visibility of response forces, and their remaining capability" (page 401). Lung et al. (2018) study an IoT Smart City concept and describe technology that can be used in an emergency management context. Endedijk et al. (2018) focus on medical emergency team interactions, and use different sensors to capture this, including sociometric badges, video cameras and a body sensor to measure the stress level. The objective was to learn more about how team interactions affect the work performance.

Even though it is easy to find previous studies on the technical requirements and the development of sensor networks for use in emergency response, the benefits from a logistics point of view are in the best case only described on a general level. In this paper, detailed logistic benefits are identified based on professional emergency response training exercises. These are then utilized as a base for a sensor requirement analysis.

METHOD

This research is based on a literature review and observations. The literature review centered on emergency management and logistics, coupled with sensors and sensor networks, whereas the observations were explorative (Yin 2009). This study used a case study method in line with Yin (2009), consisting of the following stages: plan, design, prepare, collect, analyze, and share. The main sources of case information are direct observations made by researchers, field notes, photo, video and audio recordings, and data from semi structured interviews with participants and relevant personnel. The collected data was after each observed exercise summarized by each data collector and thereafter structured into a common database. The conclusions was drawn by analyzing the structured data and were hence validated through triangulation with multiple sources of information. In addition, more than one observer/researcher observed each exercise (see Table 1). The data collection was performed at seven different emergency response exercises. The authors were not involved in the planning or organizing of any of the observed exercises.

Table 1. Data collection process and conditions

Scenario	Observed by	Data collected by	External conditions.
1: Antagonistic attack	Researcher 4, 5.	Field notes, photo, video, audio, interviews.	Daylight, clear weather, about 8 degrees Celsius. (all)
2: Airplane emergency landing and fire	Researcher 1, 2, 3, 4, 5.	Field notes, photo, video, audio, interviews.	Daylight, clear weather, about 6 degrees Celsius. (all)
3: Major traffic accident with bus crash	Researcher 1, 2, 3, 4, 5.	Field notes, photo, video.	Daylight and clear weather (1, 2, 4), morning and fog (5), about 10 degrees Celsius (all).
4: Fire at a large teenage party	Researcher 1, 2, 3, 4, 5.	Field notes, photo, video, audio, interviews.	Daylight, clear weather, about 10 degrees Celsius.
5: Suburban riots	Researcher 1, 2, 3, 4, 5.	Field notes, photo, video.	Daylight, clear weather, about 10 degrees Celsius.
6: Traffic accident with minibus	Researcher 2, 3, 4, 5.	Field notes, photo, video.	Daylight, clear weather, about 10 degrees Celsius.
7: Minor traffic accident with car	Researcher 2, 3, 4, 5.	Field notes, photo, video.	Daylight, and dusk, clear weather, about 10 degrees Celsius.

Observations

The scenarios for the different exercises that were observed in this study are summarized in Table 2. The exercises were conducted by different organizations and for different learner groups (from professional responders to rescue service and ambulance nurse students). Some exercises lasted less than an hour, others up to four hours. Participating organizations ranged from fire and rescue services, police, emergency medical services (EMS), airport fire and rescue, and military forces.

Table 2. Observed scenarios

Scenario	Description
1: Antagonistic attack	This exercise scenario featured a truck carrying a bomb that had been driven on a pedestrian street in an average sized town. Additionally, a car with two people crashed into the truck and the persons were trapped in the car. The scenario featured multiple casualties on the street, and a general level of unrest in the city. The driver of the truck was still in the driver's seat. The rescue personnel also had to deal with the risks from the not yet detonated bomb.
2: Airplane emergency landing and fire	In this scenario an airplane performed an emergency landing and caught fire close to an airport. There was a large fire and a large number of casualties at the site and in the airplane. The initial response was by airport fire and rescue and then joined by additional municipal rescue services, EMS, and police to perform life-saving medical interventions, evacuate the airplane, organize transport logistics, and search for missing people.
3: Major traffic accident with bus	In this scenario a large bus containing about 40 passengers collided with a car, and the bus overturned to its right side. Many passengers were injured with a broad range of traumas. One patient was trapped in the car and several people were trapped in the bus.

crash	Emergency response was performed by the rescue service, EMS and police.
4: Fire at a large teenage party	This exercise scenario featured a house fire at a large party. Several intoxicated minors were still inside the house, some were gathered around the house, and some were missing in the nearby woods. Some traumatic injuries were sustained after self-evacuation from windows; other injuries were sustained from burns and smoke inhalation. Further, one car had been stolen and another car vandalized, and there was reason to suspect that the fire had been started intentionally. Police, rescue services, and EMS performed a joint response to manage the accident site.
5: Suburban riots	In this exercise scenario the emergency response organizations encountered a hostile mob vandalizing cars and setting them on fire. A victim was trapped under a burning car behind the mob. The exercise was primarily aimed at police students to train crowd management and control, de-escalation techniques, and creating a safe working environment for the rescue service and EMS students who needed access to the wounded victim.
6: Traffic accident with minibus	This exercise featured a minibus that had crashed into a wall. One deceased victim was outside the vehicle, and another person had severe trauma and needed immediate life-supporting first aid. The scenario was complicated by the fact that the minibus contained undocumented refugees that had large difficulties communicating with the police and the EMS, and who may have been the victims of human trafficking. The driver of the minibus was missing.
7: Minor traffic accident with car	In this short exercise scenario, a single vehicle had crashed on a road, and one person was trapped in the driver's seat with moderate trauma. A few other people were gathered around the car, some who might have been passengers, and some who appeared to be affected by alcohol and/or narcotics.

To describe the observed general site management, operations are led by a joint command consisting of a Rescue commander, an EMS commander and a Police commander from a joint command and control site. Alerted response units can be routed to a point of stand-by (a rendez-vous point at the outer cordon). At the incident site, casualty clearing stations, field first aid posts and areas for deceased, injured, uninjured, and goods are set up as needed. At the ambulance loading site, the injured are picked up by ambulances and potentially other improvised patient transport vehicles.

Different operations that commonly occurs are: 1) reconnaissance of the site to get a full picture of the event, 2) securing the site by eliminating further threats, as well as neutralizing aggressive individuals, disarming explosives, extinguishing fires, etc. 3) triage (initial prioritization) of patients, tagging them green, yellow or red (or black if dead), 4) performing primary treatment, 5) performing evacuations, 6) loading and transporting patients to hospitals, among others.

Data collection

During the exercises, photographs were taken as well as video and audio recordings. In addition, field notes were gathered during the observations, along with notes from semi-structured interviews with exercise participants and managers. These field notes and the observers' general impressions were aggregated through group discussions. Each observation was focused on potential issues and problems where sensors might be helpful to the situation, in particular where they potentially could contribute to better logistics and planning. Other particular points of interest included what type of information the exercise managers could use for a more robust and detailed evaluation, what information they would need to determine the success of the exercise, and what challenges the evaluators faced in terms of keeping track of the progression of the exercise.

RESULTS

The results are presented in two sections. The first section describes the potential benefits of using sensors to capture data, and the second specifying the necessary requirements for the sensors.

Potential benefits from using sensors

From the observations of the different scenario exercises, several potential benefits from using more advanced sensors and sensor networks for exercise tracking and evaluation were found. These benefits are summarized in Table 3.

Table 3. Potential benefits of using sensors

Potential benefit	Description
Operational resource overview	It is a challenge to keep track of all resources, personnel as well as vehicles and equipment. If these were tagged with a sensor that could transmit an accurate location of the resource, that would help to provide a good situational awareness for the command. However, in the many of the scenarios, the incident site was spatially limited, e.g. about 50x50 meters in Scenario 3. This requires the sensors to provide a very fine spatial resolution, to support decisions. The Rescue commander usually uses a whiteboard to create an overview of the event and the evolvement of the rescue operations. Together with the other commanders, (s)he goes through an overview of the response objective, inventory of casualties, what needs to be done, how to prioritize, what resources that are available, where to collect wounded, current and possible threats, how to communicate, and dividing resources into groups or sectors with different tasks as needed. The meetings are short and repeat every 30-60 minutes. During such meetings, a list or map with sensor data (at least position) of the involved patients, casualties, resources and equipment would be of great help.
Patient tracking	A major issue in several of the scenarios was to keep track of casualties, e.g. how many and where they are at the different stages of evacuation and treatment. To have good knowledge of each patient's status and location is paramount for effective treatment and transportation planning. In some scenarios, patients that should have been highly prioritized were overlooked while low prioritized patients were assigned to ambulances. Also, at the end of the exercises, when checking how many patients that had been transported away from the incident site, this number seldom matched between the different response actors, and with the number of people who actually were transported.
Digital triage	When performing triage, the patients get a tag of a certain color depending on the severity of the injuries and the urgency of medical intervention. A sensor that can be used to track the patients can also double as a triage tag if coupled with some form of input device (e.g., mobile device) where the medical staff can register the necessary data. It would also need lights in the correct colors. One benefit compared to regular triage tags, apart from the patient tracking, is that it would be easier to update if the patient status changes or a misdiagnosis is identified. If the sensors themselves are capable of monitoring basic vital parameters, such as heart rate, breathing rate, body temperature or blood pressure, or are capable of connecting to other medical sensors, they could potentially be used to alert medical staff of critical changes in the health status of patients.
Position capture for post-event analysis	With position and time stamps for all resources and patients, it would be possible to do a detailed and thorough post-event analysis of the operations to identify possible improvement opportunities. Again, a high spatial and temporal accuracy is important.
Communication and team interaction analysis	While positions and time stamps would give some insight into the operations, the communication between the responders is vital for a deeper understanding. Most decisions are made in collaboration between different organizations, or as a result from joint decision making. Thus, to be able to fully analyze the operations, communication both over radio/data and verbally (face-to-face) between responders must be captured. To avoid having to do speech analysis, it may in some cases be enough to capture that certain people have communicated, but not necessarily what was said, or capturing certain vocal elements (pitch, frequency, amplitude) for a rudimentary analysis of how things were said. And in the case of patients, that the most critical are regularly reassessed.

Sensor requirements

In order to achieve the potential outlined in the previous section, the sensors have to fulfill the requirements listed in Table 4.

Table 4. Sensor requirements

Requirement	Description and motivation
ID	The sensor must have a unique identification that is associated with all transmitted data. This to be able to associate it with the object (resource or patient) to which it is attached.
Simple interaction	It is necessary to easily be able to input information about the object into an information system, which will manage the information transmitted by the sensors. This could be used to e.g. to assign the sensor to a patient or staff role, or assign a triage priority.
Physical attributes	The sensor needs to be small, robust and easy to carry. It must also be able to be securely attached to clothes, tools, or persons. The environment where the sensors are expected to be used is often harsh, so they need to be able to withstand high temperatures, wet environment, chemicals, punches and bumps.
Position capture	The device should be able to know its position with a high accuracy, both outdoors and indoors. Thus, just relying on Global Navigation Satellite Systems like GPS might not be enough. Like in Zhang et al. (2013), complementing technology can be used to improve the indoors accuracy.
Movement and orientation capture	The device should be able to measure movement along all three axes, e.g. in order to determine if person is standing or laying down. This can be used to improve positioning accuracy, and also to determine sudden movements that may be due to falls, dropped equipment, or sudden deterioration of patient status.
Time stamps	All collected data must be accurately timestamped. This to enable a post-event analysis where the sensor ID together with position and time stamps will make it possible to replay the scenario, and trace the movements of all objects.
Sound capture	By being able to capture sound and speech, it is possible to analyze communications and team interactions. Together with position and time stamps, captured communication between objects will help when analyzing who did what and why. This gives a solid base for improved learning and finding improvement opportunities.
Proximity to other sensors	If two sensors have been close to each other for some time, it is possible to assume that they have interacted, e.g. an ambulance nurse reassessing triage on a patient, or a fire fighter picking up a specific piece of equipment. This is another way of overcoming inadequate positioning accuracy, and to ensure that interaction between objects is identified.
Temperature capture	To register the temperature would be useful especially when analyzing firefighting operations. It can also be used to study how the surrounding temperature affect the stamina of the response personnel or the state of the patients.
Data storage	For post-event analysis, it must be possible to securely send data in real time to a server, alternatively to store data on the sensor. Sending directly to a server is preferable, since then it is not necessary to transfer the data from the sensors afterwards. Also, if capturing space consuming data like speech, the sensors would need a lot of storage space. The drawback with sending the data to a server, is that the data communication has to be reliable and secure.
Real time data and communication	For operational usage, it must be possible to send data in real time to a server, and possibly to other sensors. While commercial communication networks, like e.g. 4G, in general are quite reliable and have enough capacity, given an emergency scenario, it is possible that the capacity and capability of these will be affected. Then, complementary technology, like e.g. wireless ad hoc networks (see e.g. Ray and Turuk, 2017), can be used to ensure reliable communication.
Battery	The battery time needs to be sufficiently long to operate for a number of hours without requiring additional charge. A few hours up to a day is usually sufficient for training and exercise purposes. Then, the batteries can be recharged. For usage in a real scenario, the battery time might need to be severely improved, depending on the event. For many natural disasters, e.g. forest fires and floods, the response phase might have a time span of days or weeks. In these cases, it would be inconvenient if the sensor batteries had to be charged once every 24 hours.

DISCUSSION AND FUTURE WORK

The current results show that using advanced sensors and sensor networks at emergency incident sites might bring significant benefits, in particular regarding situational awareness, resource and patient tracking, and communication and team interaction analysis.

A concrete example of how this could be used, is in an exercise setting, like in one of the observed scenarios. Before the exercise, all objects (response personnel, critical equipment and victims) are tagged with a sensor, and all necessary information about the object is registered. During the exercise, the sensors send their positions (and other information) to an information system, capable of visualizing the positions and possible statuses (e.g. triage) on map, facilitating a good situational awareness for commanders and exercise management (or only for exercise management, if commanders are not supposed to have access to such decision support). After the exercise, the recoded data can be used by exercise management, e.g. in an After Action Review (AAR), to illustrate what went well, and what could have been done better. Furthermore, operations analysts can also use the data to adapt and develop theory and build models explaining and supporting emergency response operations. These can then be used to analyze and evaluate the exercise, as well as identify improvement opportunities. For example, it may be possible to see that the ambulance loading site was badly chosen, resulting in long distances where personnel had to transport patients using stretchers. Or that it would have been better to concentrate the firefighting efforts at another place initially, which would have resulted in less damaged infrastructure.

While these are expected results, in line with previous research, most focus has earlier been to provide the technical platform for the data capture. There has not been much extensive work on how this data actually should be used in a post-event analysis phase to find improvement opportunities and provide planning insights.

Thus, the next steps in this work are to:

1. Build or acquire sensors that can capture the necessary data
2. Perform exercises and experiments
   a. Tag resources (personnel, vehicles, equipment) and patients
   b. Collect data during the exercise
3. Analyze data from the experiment
   a. Based on logistics theory
   b. Using artificial intelligence (AI)
4. Develop models / methods / guidelines for how the operations can be improved
5. Collect feedback and repeat the steps above in order to refine and fine-tune

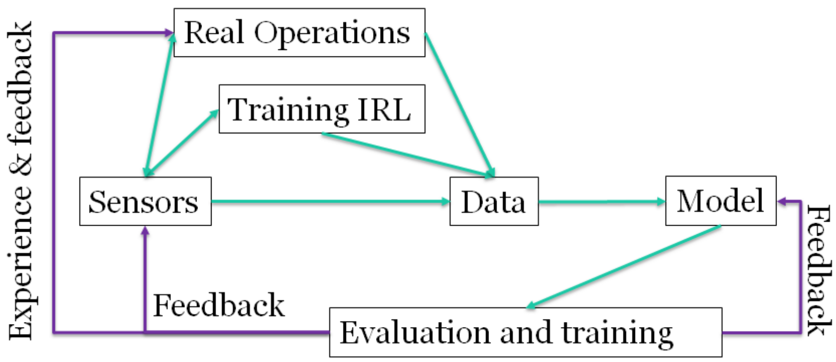

Figure 1. Future data collection system

A possible future data collection system is outlined in Figure 1. Sensors will be used to collect data both from exercises and from real operations. The data will then be analyzed using adequate models, methods and theories, which will give results that can be developed into improvement suggestions and decision support tools. These can then be tested and trained in exercises, possibly through simulation or e-learning (as e.g. suggested by Taber, 2008). Using the models is furthermore expected to give feedback into how they can be updated, as well as how to continuously develop the sensors and the data capturing systems, and most importantly, how real operations can be improved.

CONCLUSION

The operations at an emergency incident site are often fast paced and require some amount of improvisation. Furthermore, there is usually a multitude of resources, injured and bystanders interacting. This often makes it difficult to document and collect data, which makes it hard to both provide relevant information during operations and afterwards, retracing exactly what happened. Advanced sensors and sensor networks could help in this. By capturing position and communication between everyone involved in the operations, it should be possible to use logistic theory to analyze the operations and suggest improvements. However, it is a challenge to construct sensors that fit all requirements, in particular on the spatial indoor accuracy.

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