Modeling of Crisis Management Systems: Results of a Systematic Literature Review

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ABSTRACT

Models are important means to represent, explore, evaluate, and develop systems, such as interorganizational crisis management (ICM) systems. The objective was to explore how ICM systems are represented in the scientific literature, i.e., how ICM systems are modelled. The study was carried out as a systematic literature review. The results are presented as (1) organizational descriptions or models of ICM systems, (2) functional components of ICM systems, (3) analytical approaches used to model ICM systems, and (4) changes of ICM systems. The results revealed that ICM systems are described in various ways, and that descriptions of models are rather based on entities developed by the authors of the publications than on a common framework for describing ICM systems. The identified information on models, functional components, analytical approaches, and changes of the ICM systems provide important input to future work, e.g. comparing different models to determine their strengths and weaknesses.

Keywords

Interorganizational Crisis Management, Crisis Management, System Model, Literature Review

INTRODUCTION

Crises are events that fall outside the scope of what is normal and expected. Severe crises run the risk of having a major impact on societal values, such as human lives and well-being, infrastructures, and societal functions (Boin, 2009; Borodzicz and Van Haperen, 2002). Examples of severe crises are the Indian Ocean tsunami (2004), the World Trade Center terrorist attacks (2001), and the mega forest fires in eastern Australia (2019-2020) (Geist, Titov and Synolakis, 2006; Nolan, et al. 2020; Huddy and Feldman, 2011). Due to the scale, complexity, and unpredictability of severe crises, these cannot be handled by single organizations. Hence, organizations engaged in the handling of such crises need to collaboratively partake in interorganizational crisis management (ICM) responses, which puts pressure on those organizations to coordinate their efforts. The interorganizational context requires that crisis management (CM) organizations establish a trust and understanding of each other's roles and responsibilities, share information, coordinate their efforts, and establish situation awareness (Granåsen, Olsén and Oskarsson., 2018; Granåsen, Olsén, Oskarsson and Hallberg, 2019). Hence, ICM responses are complex operations that are difficult to fully overview. In this respect, one approach to support the understanding of ICM responses is the general system theory, which makes complex occurrences more tangible (von Bertalanffy, 1969).

There are several definitions of the term *system* (ISO/IEC/IEE, 2010; Hallberg, Jungert and Pilemalm, 2014). However, systems are generally regarded as a set of interacting elements organized to accomplish a specific function or goal, and with the ability to interact with the environment. The concept system can be used as a perspective for looking at a delimitate part of the world as a unit consisting of interacting components. Hence, it is possible to view a car as a system consisting of interacting components that are assembled to accomplish a well-defined goal (Friedenthal, Moore and Steiner, 2014). Even though it is possible to consider almost everything as a system, such as mathematics, the solar system, the Internet, humans, political systems, and community infrastructure, considering everything as a system is not useful.

Models are abstract representations of phenomena (Lawson 2010) and may, for example, be used to explore, document, and discuss phenomena such as systems. Models need to have a clear and stated purpose, otherwise they risk becoming excessive, inaccessible and unclear. In systems engineering, models are fundamental for the understanding of existing systems as well as for the design of new systems (Hay, 2003; Hallberg et al., 2014). In general, two major types of models are used within systems engineering (Friedenthal et al., 2014; Hallberg, Granåsen, Josefsson and Ekenstierna, 2018). Firstly, there are those that describe the structure of systems, e.g., tree diagrams and class diagrams (Tague, 2005; Fowler, 2004). Secondly, there are those that describe the behavior of systems, e.g., activity diagrams, use case maps, and sequence diagrams (Fowler, 2004; Ölvingson, Hallberg, Timpka and Lindqvist, 2002). There are also frameworks that bring together several models to view systems from several different perspectives, e.g., enterprise architectural frameworks (Zachman, 1987). This means that models can be used to analyze the system, explore and evaluate the system's design and, further, how the system can be affected in order to obtain a desired behavior. An existing system's behavior, such as an organization, can be affected by the reengineering of work procedures and introduction of information systems.

ICM responses are complex and it is therefore difficult to obtain a full overview and understanding of them. This is further complicated by the fact that each crisis is unique in many respects. Modeling may thus be a viable approach to be able to understand and develop ICM systems. However, there exist an extensive number of notations for system modeling, and it is not clear which notations are the most suitable to model ICM systems.

The objective of this work was to explore how ICM systems are represented through models in the scientific literature. The analysis was based on a previously performed systematic literature review (SLR) and concerned four types of ICM perspectives with relevance to modeling of ICM systems:

- Organizational descriptions or models of ICM systems.
- Functional components used to describe ICM systems.
- Analytical approaches used to model ICM systems.
- Changes of ICM systems – suggested in studies.

METHOD

The previously performed systematic literature review (SLR), on which the analysis was performed consisted of two parts - assessment of ICM capability and modeling of ICM systems (Granåsen et al., 2018, 2019). The database Scopus was used for the literature search and was limited to publications from 2012-2017. Abstracts of 1,197 potentially relevant publications were reviewed. This resulted in the identification of 166 publications for full text review. The full text review of these papers and 17 others identified by snowballing resulted in the identification of 77 papers on modeling of ICM systems. The SLR and the results of the assessment of ICM capability were extensively reported in Granåsen et al. (2019). However, the results on modeling of ICM systems presented in this paper have not been previously reported.

The analyses of each type of ICM system perspective were performed in three steps:

1. Extraction of SLR questions that contained information on the ICM system perspective.
2. Review of the notations of the review questions in the SLR.
3. Short review of the abstract and paper of each publication on the topic.
4. Categorization of extracted information on the topic.

The analyses were iteratively performed by two researchers. An explorative approach was used, meaning that the categories were dynamically formed during the analyses.

Three review questions in the SLR were specifically related to modeling of ICM systems. Table 1 describes how these questions were used for the analysis of each of the four ICM system perspectives in this work.

Table 1. Description of the four types of ICM system perspectives that were analyzed in this work, and the three review questions used in the SLR

Analysis in this work	Review question in SLR
Organizational descriptions or models of ICM systems.	Does the paper describe a crisis management system?
Functional components used to model ICM systems.	
Analytical approaches used to model ICM systems.	Does the paper address/describe system analytic approaches for identifying the components and relations (model the system)?
Structural changes of ICM systems.	Does the paper address structural changes resulting from the crisis?

RESULTS

Of the 77 publications in the SLR that provided information related to modeling of ICM systems, 40 included organizational descriptions or models of ICM systems, 67 described functional components of ICM systems, 44 described analytical approaches to extract or analyze ICM systems, and 15 papers described changes of ICM systems. The number of organizations described in each of the 77 publications are illustrated in Figure 1. The majority of the publications with unspecified number of organizations comprised developments of general frameworks.

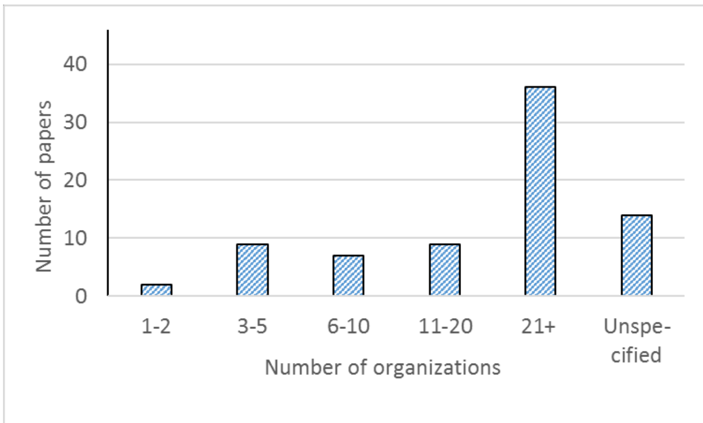

Figure 1. Number of organizations included in the analysis of ICM in the publications

Organizational descriptions or models of ICM systems

40 (52%) of the 77 publications in the SLR contained organizational descriptions or models of ICM systems. Most publications described large-scale disasters - natural disasters, acts of terror or mechanical incidents such as ferry disasters or accidents in large industries. In the analysis, the organizational structures or models of ICM were divided into three types: (1) regional or national incident management systems, (2) ICM systems in relation to a specific disaster, and (3) general organizational models of ICM systems.

National or regional incident management systems

The descriptions of national incident management systems included, for example, a model of oil spill responsibilities in Sweden, a reference model of Queensland disaster management, the Australasian Inter Service Incident Management System (AIIMS), the Norwegian emergency management system, and an organizational chart of the Multidisciplinary command and information in the Netherlands.

The model of oil spill responsibilities in Sweden describes participating organizations and their responsibilities, and includes four categories of organizations (Pålsson, Hildebrandt and Lindén, 2018):

- One organization with responsibility for sea response: the coast guard.

- Three organizations with responsibility for onshore response: municipalities, county administrative boards, and agencies.

The reference model of Queensland disaster management was developed by Andargoli, Bernus, and Hadi (2013), with the purpose to improve interoperability in the Queensland disaster management system. The model describes the disaster management system and important interoperations between entities. It was developed by the generalized enterprise reference architecture and methodology (GERAM) framework, with the motivation that it contains three important entities: complete life cycle coverage of all entities, equal consideration of both human and technical system views, and the ability to demonstrate the relations between life cycles and life history of included entities.

The Australian Inter Service Management System (AIIMS) is a policy framework to guide Australian CM (AFAC, 2011). It describes four main organizational components of CM: planning, public information, operations, and logistics. According to Owen et al. (2013), AIIMS clearly describes local CM, but is less clear on roles and responsibilities on regional and state levels.

The organizational chart of multidisciplinary command and information in the Netherlands is a three-tier system, which is enshrined in the law and includes: (1) municipal or regional disaster teams, (2) regional tactical teams, and (3) local operational command teams. The chart describes hierarchical relations between the teams in relation to implementing field units and operation action centers in the case of full escalation (Sholtens, Jorritsma, and Helsloot, 2014).

The general description of a Finnish search and rescue organization in Seppänen, Mäkelä, Luokkala, and Virrantaus (2013) provides a model of an ICM system in four parts: Command body of the area of operations, Command body of supporting services, Command centre of regional rescue services, and Emergency response centre (Figure 2).

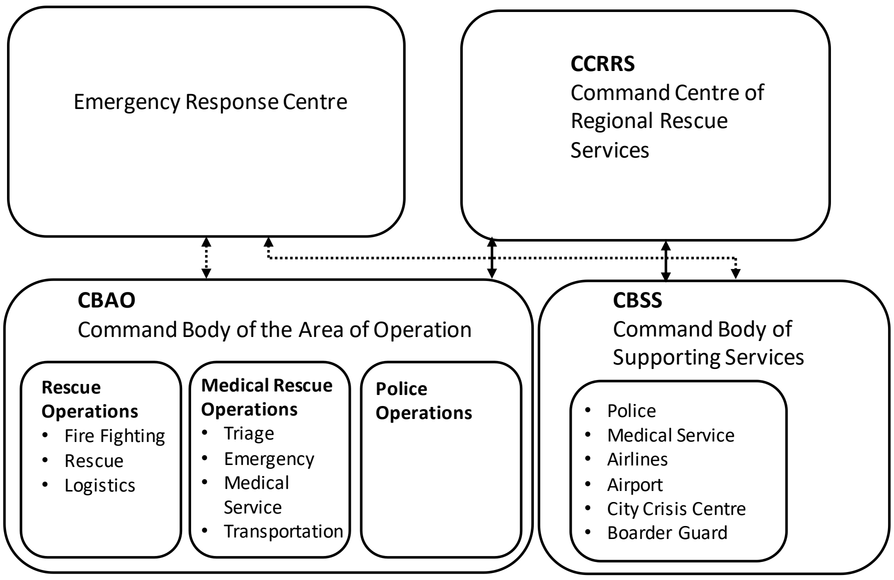

Figure 2. Schematic illustration of the Finnish search and rescue organization (adapted from Seppänen et al., 2013)

ICM systems related to specific disasters

The descriptions of ICM systems related to specific disasters included information about the specific actors involved in the disaster and the relationships between them. Several papers described how organizational structures were formed ad hoc, as the crisis evolved. A significant portion of these models were extracted through social network analysis.

General organizational models of ICM systems

The descriptions of general organizational models comprised typical ICM systems with different types of actors that were not tied to a specific nation or crisis. This category further included models that describe the organization of an ICM coordinating function during ICM operations, without specifying the other crisis management actors involved in the crisis (Bearman, Grundwald, Brooks and Owen, 2015; Sundnes, 2014). A comparison between the organizational structures in routine work and during disaster response was provided in Guo and Kapuco (2015), and is schematically illustrated in Figure 3.

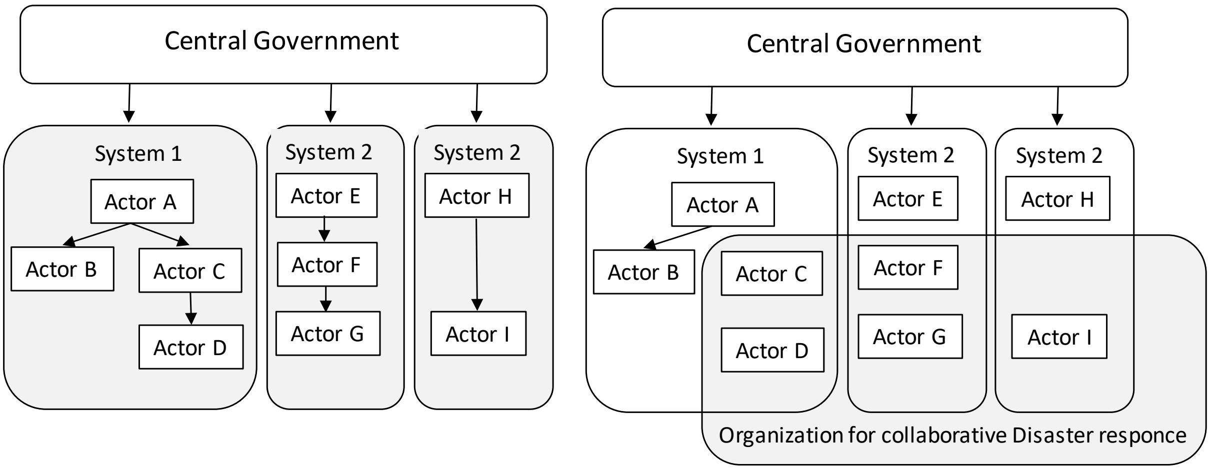

Figure 3. Schematic illustration of the difference between two organizational structures of ICM in routine work (left) and during disaster response (right) (adapted from Guo and Kapuco, 2015)

A further example include an organizational model of emergency response comprising operational centers of three organizations: fire, police, and emergency medical services and their interactions and dependencies on strategic and tactical levels. This model was developed by Saoutal, Cahier, and Matta (2014) with the purpose of studying activity and communication in ICM crisis management.

An example of a model representing the organizational structure of a typical Incident Coordination System described by Sundness (2014) is schematically illustrated in Figure 4.

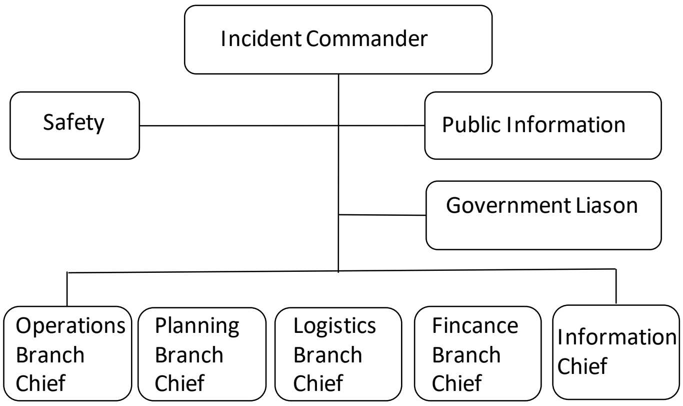

Figure 4. Schematic illustration of the organizational structure of a typical Incident Coordination System

(adapted from Sundness, 2014)

In summary, the organizational models generally described the roles and responsibilities for specific circumstances, resulting in a diversity of organizational descriptions. Moreover, the systems were described on different levels and with different components.

Functional components of ICM systems

Sixty-seven (87%) of the 77 publications in the SLR contained information about functional components of ICM systems. Functional components are in this paper defined as entities used for describing the behavior in an ICM system. The majority of the publications contained analyses of a specific case, for example, Giordano et al. (2017), who described the emergency management system for flooding in Lorca, Spain (Figure 5).

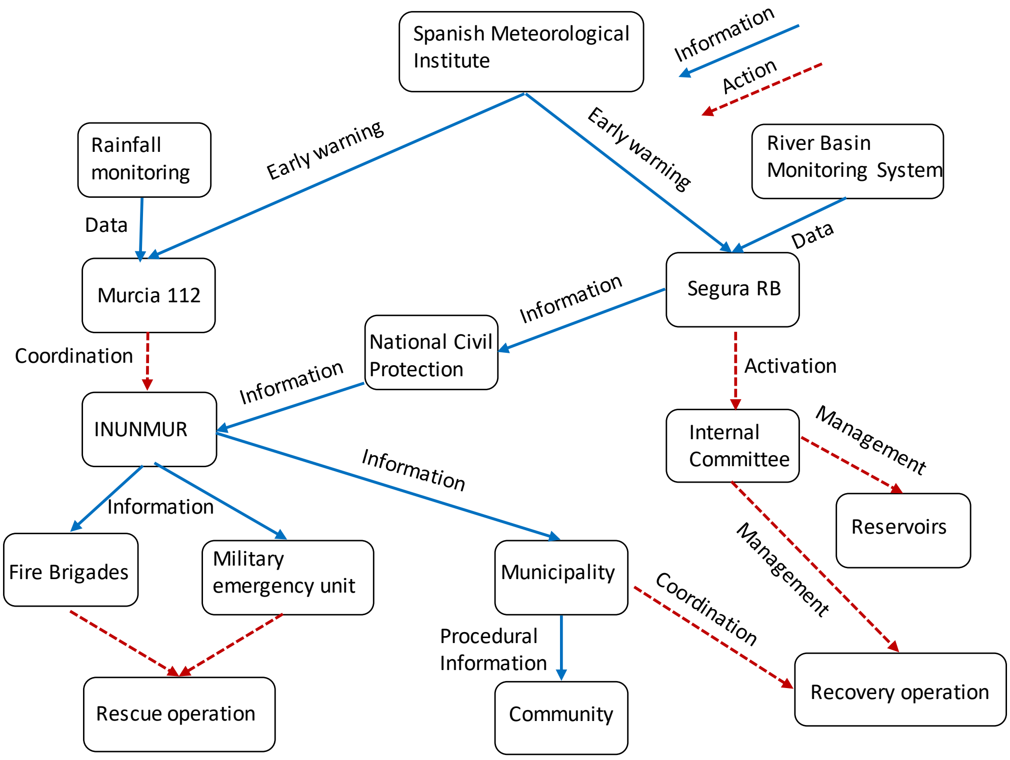

Figure 5. Illustration of the emergency management system for flooding in Lorca, Spain (adapted from Giordano et al., 2017)

Categorizing the functional components identified in the various publications was challenging due to inconsistent use of terminology between publications, as well as a lack of definitions of terms in the publications. Thus, the results were arranged into general categories. Some functional components described the relations between actors, such as information, management and coordination, as shown in Figure 5. Other components described behavior that is not easily visualized in a model. In the analysis, the functional components were arranged into nine categories (Table 2).

Table 2. Categories of functional components used to model ICM systems

Number of publications	Categories of functional components of ICM systems
38	Information exchange and unspecified interaction
20	Collaboration
18	Coordination
18	Command, control, and management
14	Obtaining situation awareness
11	Planning
11	Adaptation
9	Task interdependency
6	Interoperability
4	Trust

Information exchange and unspecified interaction mainly refers to socio-technical aspects of information transmission between participating organizations. Publications in which the content of the communication between the actors was unspecified contributed to this category. The analyses conduced in the publications were largely based on communication density in terms of number of messages sent rather than on information content. Communication was frequently studied and modeled by social network analysis (SNA) (e.g. Bdeir, Hossain and Crawford, 2013; Schweinberger, Petrescu-Prahova and Vu, 2014). Some of the publications that were assessed as studying unspecified interactions presented their studies as studies of collaboration. However, if the study did not contain information about the organizations actually conducting the collaborative work, it was still considered to belong to the unspecified category. In one paper this was expressed as "simply being part of the same network does not suffice for it to be labelled actor collaboration" (Hermansson, 2016).

Collaboration refers to how participating organizations work together to solve crises. A few papers denominated this as cooperation rather than collaboration. Bodin and Nohrstedt (2016) investigated how individual actors select collaboration partners and tasks in the formation of a collaborative crisis network, which they hope will contribute to more effective collaboration approaches for CM. Bang and Kim (2017) suggested an analytical framework of the disaster management process to examine how the collaboration process proceeded and why it did not work properly at the site of a ferry disaster in Korea.

Coordination refers to alignment of the CM organizations' actions towards a common goal. Formalization and strengthening of the roles of central organizations in order to improve coordination of Swedish oil spill resources was studied by Pålsson et al. (2017). Curnin, Owen, Paton, and Brooks (2015) presented a theoretical framework for facilitating coordination of CM.

Command, control and management refers to formal and informal hierarchies focusing on leadership, governance and decision making authority. Sundness (2014) provided models of both a typical incident command system where the incident commander is in charge, with responsibility of the overall operation, and a model with unified command, which is used in most emergency operation centers. Sundness (2014) emphasized that a command and control center always needs mandate, power, and resources to accomplish any CM operation.

Adaptation includes a collection of perspectives related to learning, making use of experience to improve the system, system changes, improvisation, and adaptive capacity. Two examples of system descriptions contributing to this factor were an adaptive and integrated disaster resilience framework developed by Djalante, Holley, Thomalla and Carnegie (2013) and a conceptual framework concerning adaptive capacity of the disaster response system by Gero et al. (2015).

Planning refers to preparations before a crisis by planning both procedures within organizations and collaboration between organizations. Pålsson et al. (2017) presented a Swedish oil spill planning network arranged by the organizations' relative importance.

Obtaining situation awareness (SA) is a summary category that refers to functional components related to gaining an understanding of the situation. Sensemaking, situational assessment, and shared awareness were other terms used in this category. While SA is primarily centered around the activities of understanding the crisis, *task interdependency* focuses on the understanding of the roles and tasks of other organizations, as well as how one's own organization fits into the puzzle.

Interoperability refers to the ability of two or more organizations to operate together. Technological, cultural and methodological interoperability were addressed, including language issues. One paper studied interoperability in the Queensland disaster management system (Andargoli et al., 2013), using the definition by Chen (2006), which is more complete and holistic compared to some other interoperability frameworks.

Trust included publications that addressed the importance of trust in the ICM system as a prerequisite for well-functioning collaboration.

The different functional components are interrelated, and used in various ways in various system models. Obtaining situation awareness may, for instance, be an input factor in one model, while it is the output in another model. Information exchange is a way of obtaining situation awareness as well as understanding the roles of other organizations. Most papers addressing information exchange focused solely on that factor. However, other publications presented models that included a multitude of aspects, or several models depicting different perspectives. One example is Bergström, Uhr, and Frykmer (2016), who suggested six interpretations of how coordination was achieved between CM organizations during a major wildfire, for example, viewing the CM system as a system of communication, a system of formal relations, or a system of trust.

Analytical approaches used to model ICM systems

Forty-four (57%) of the 77 publications in the SLR contained information on analytical approaches used to model ICM systems. In all, 56 analytical approaches were identified, meaning that each of the 44 publications on average contained information on 1.3 analytical approaches. Six categories of analytical approaches used to model ICM systems were found in more than one publication (Table 3).

Table 3. Categories of analytical approaches used to model ICM

Number of publications	Analytical approaches used to model ICM systems
26	Social network analysis (SNA) and network analysis
3	Communication analysis
2	Activity theory
2	Content analysis
2	Coordination theory
2	Situation awareness (SA) assessment

Examples of analytical approaches used to model ICM systems that were only found in one publication include boundary analysis, business process modeling, normative framework for systematic assessment of coordination, and the recognition primed decision model.

Social network analysis (SNA) and network analysis were without comparison the most frequently used analytical approaches to model ICM. Different types of data, for example, interviews, newspapers or audio recordings, were used for the SNA analyses to discover and investigate networks that occurred during CM. Amongst other things, SNA was used to model interactions between actors (Giordano et al., 2017), resilience (Jung, 2017), and centrality between different organizations (Marcum, Bevc and Butts, 2012).

Communication analysis was used by Trnka and Johansson (2011) in a bottom- up approach to investigate the interactions between emergency commanders in a simulation game. Communication analysis was also used to study communication flows between different levels of commands (Saoutal et al., 2014), or within a team (Baroutsi, 2016).

Content analysis was, for example, used in a case study of the emergency response at a school shooting, where data was structured into three themes: information flow, challenges, and actions implemented (Norri-Sederholm, Paakkonen and Huhtinen, 2016).

Activity theory is a method for creating an understanding of activities in a context and observing inter-connectivity between different networks. Furthermore, it also makes it possible to understand the informal roles and norms that underpin organizational activity and how they affect interoperability and information sharing (Allen, Karanasios and Norman, 2014).

Coordination theory was, for example, used to extract elements of coordination processes, such as actions, actors, and resources that were used as components of the suggested model (Noori, Paetzold and Vilasis-Cardona, 2016). Dowell (2016) examined coordination in ICM teams to identify factors relating to planning, action, communication and knowledge of the ICM system.

Situation awareness (SA) assessment was used as an analytical approach in two publications. Subjective self-ratings of participants by the situational rating technique (SART) was used to assess if the introduction of a team coordinator increased team SA (Van de Walle, Brugghemans and Comes, 2016). A study of breakdowns in communication during CM of bushfires in Australia analyzed how this lead to differences in understanding between team members (Bearman, Grunwald, Brooks and Owen, 2015).

Changes of ICM systems

Fifteen (19%) of the 77 publications in the SLR contained information on changes of the ICM system. In all, 25 descriptions of changes of the ICM system were identified, meaning that each of the 15 publications that contained changes of the ICM system on average described 1.7 changes. Seven categories of changes of the ICM system were identified in the analysis (Table 4)

Table 4. Categories of changes of the ICM system

Number of publications	Changes of the ICM system
6	Organizational
3	Collaboration
3	Planning
2	Communication
2	Coordination
2	Information management
2	Technical information infrastructure

Changes of the ICM systems that were only found in one publication were related to expertise, medical provision, safety policies, roles, and a shift from information management to interaction management.

Organizational changes included, for example, implementation of an ad hoc structure for the sole purpose of CM coordination during a forest fire (Bodin and Nohrstedt, 2016), involving the County Administrate Board to assume responsibility of the CM of a wildfire (Bergström et al., 2016).

Changes in collaboration entailed, for example, inclusion of other organizations in the command and coordination structure (Zhang, Zhang, Comfort and Chen, 2016).

Changes in planning mainly referred to changes of preparedness plans, for instance, implementation of decentralized network based response plans (Noori et al., 2016), and communication plans on which actors should have information, as well as what kind of information and when (Zhang et al, 2016; Rencrantz et al., 2012).

Changes of communication entailed, for example, including communication in preparedness planning (Rencrantz, Karlsson and Olsson, 2012).

Changes of coordination included a shift from a hierarchical structure towards a task based coordination (Noori et al., 2016), and the set-up of a cross-departmental task force due to insufficient coordination. This can also be regarded as an organizational change (Bang and Kim, 2016).

Changes in information management mainly referred to how information is shared between the involved organizations. However, some publications also addressed improvements of the information system (Bang and Kim, 2016), information strategy (Zhang et al., 2016), and preparedness activities (Danielsson, 2016).

Changes of technical Information Infrastructure relates to technical equipment for communication and transmission of information. One example was the implementation of a new information system to improve information sharing and cooperation (Norri-Sederholm et al., 2016).

DISCUSSION

In order to maintain and develop the capability for ICM, it is important to understand how it works and how it should work. For this purpose, models and modeling are important measures (Lawson 2010). However, what system models are suitable in the ICM field are not clear. As a result, the objective of the study presented in this this paper was to study what types of system models are used to describe ICM.

The analysis in the study presented in this paper provided an insight into what models and components are used to describe ICM systems. In general, systems can be modeled in terms of two aspects, structure and behavior (Hallberg et al., 2018).

Hence, the use of models and descriptions of organizational and functional components of ICM systems were analyzed. In general, the organizational descriptions and models of ICM systems included the roles and responsibilities for specific circumstances, which resulted in a diversity of organizational descriptions. Moreover, the systems were described on different levels and with different components.

The functional components used to model ICM systems are more disperse and were thus harder to analyze than the organizational perspective. It was difficult to categorize the functional components due to inconsistent terminology and unclear definitions. For example, the method section in the publications did not always describe to which extent the content of information shared had been analyzed.

The organizational and functional descriptions and models of ICM systems varied from simple models with rudimentary components to models of complex networks with numerous components (Guo and Kapuco, 2015; Giordano et al., 2017). The models were also used differently. For example, a functional model could either be the starting point for verification of links in the model or be used for different perspectives of the analysis or result. Irrespective of this, the inclusion of organizational descriptions of models of the ICM system facilitated comprehension of the papers. Most models were developed by the authors and did not occur in other papers. This indicates a lack of established models of ICM systems.

SNA was without comparison the most frequently used analytical approach for modeling ICM systems. Since SNA provides a structural description of the communication paths between the organizations and the importance, or roles, of the organization, its frequent use may be seen as a logical reflection of the applicability of the system modeling method. However, a drawback with SNA is that if all relevant organization or communication channels are not identified, the resulting model will be incomplete. Furthermore, SNA is generally based on logged communication, meaning that face-to-face communication will not be a part of the analysis. Finally, the SNA analyses rarely considered the content in the communication flows in the system. Thus, for a deeper understanding of the functional system, SNA needs to be used in combination with qualitative methods. In this respect it is not surprising that most publications contained relatively superficial analyses based on a number of messages sent between organizations, while only a minor part of the publications contained a deeper analysis, based on what the ICM system had accomplished.

Organizational changes was the most frequently identified type of change of the ICM system, which is highly relevant for the perspective of system modeling. The described changes generally resulted from an exercise or having handled a real crisis, while few descriptions concerned changes imposed during an ongoing event or exercise. The fact that only a few studies analyzed the impact of system change is probably a reflection of research generally being conducted within a limited time scope and focusing on analyses of specific cases. However, profound analyses of application and impact of system changes generally require long-term studies, which is not always feasible within research projects. Nevertheless, in order to support the development or transformation of an ICM system, such as its capability of adaptation, it is necessary to monitor not only what changes are implemented but also the results of these changes.

The limited number of publications related to ICM modeling in the SLR indicates that this may be a non-exploited topic. However, it cannot be excluded that publications related to modeling were missed in the SLR, since both the literature search and the original SLR review mainly focused on assessment of ICM systems. To remedy for this potential shortcoming, a complementary literature search with the sole focus on modeling of ICM systems is considered. Irrespective of this, a strength of the SLR is that it focused on empirical studies, meaning that the identified system models mainly related to actual ICM systems and were based on actual activities conducted within these systems during a crisis or exercise.

CONCLUSION

The publications identified through the SLR provided useful insight into what components are used to describe ICM systems. The results revealed that ICM systems are described in various ways in the literature and that descriptions of models are based on entities developed by the authors of the publications rather than on a common framework for describing ICM systems. Hence, there is a need for a more coherent and standardized approach to model ICM in order to enable comparisons between different descriptions and studies. The models and system descriptions extracted in the literature review provides a valuable source for creating more general system models and a more coherent terminology.

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