Developing Information Systems for Collaborative Emergency Management: Requirements Analysis and Prototyping

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Abstract. The paper presents needs and requirements for information systems support for collaborative emergency management, developed in collaboration with emergency management stakeholders in Norway. The requirements focus on three basic elements for shared situation awareness (SA) in inter-agency emergency response: terminology harmonization, map-based common operational picture (COP), and support for evaluation and learning from incidents. Building on core design principles for emergency management information systems, prototypes have been developed for these three areas and validated with potential users. The paper contributes with a user-centric approach in identifying and designing information systems support for collaborative emergency management together with stakeholders, moving from needs to requirements to design proposals and covering core elements of COPs needed for shared SA. The collected requirements and prototypes developed may serve as a basis for further development of standardized solutions for inter-agency emergency operations.

Keywords: Emergency management · Common Operational Picture · Situation Awareness · User participation · Design principles · Terminology harmonization · Map support

1 Introduction

The recent decades have witnessed an increase in frequency and severity of natural and man-made disasters, requiring large-scale and complex response operations involving extensive inter-agency collaboration. During any disaster, there is a need to make quick, correct, and strategic decisions at different organizational levels and among the agencies involved. Adequate decisions in turn depend on high-quality situation awareness (SA), i.e., the perception of environmental elements and events concerning time or space, meaning, and their future status [1]. Establishing SA is often challenging at the individual or team level and even more so when joint SA across agencies must be achieved.

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The use of information systems (IS) for developing and presenting common operational pictures (COP) supporting joint emergency response is one approach to improved SA [2, 3]. Even if COPs lack a univocal definition, they can be seen as a structure for available information to be collectively transformed by the actors into knowledge and a representation of this knowledge that provides a process and basis for further decisions and actions [4]. COP solutions often incorporate the use of geographical information systems (GIS), to be able to visualize the locations, available resources, and dynamics of a crisis event on a map. However, COPs also come with multifaceted challenges: lack of a systematic overview of information elements that are critical to share in different crisis scenarios; lack of a common map interface in place using standard symbols; and different terminologies used across disciplines, resulting in possible communication and coordination problems [5]. Further, even with access to a shared COP, this may still result in multiple interpretations and a lack of a common situational understanding among the actors involved [4, 5].

Almost two decades ago, Turoff et al. [6] presented fundamental design principles for developing a general "dynamic emergency response management information system", one of these principles being that such a system needs to support "an open and flat communication process". Yet, emergency management (EM) practice is still characterized by uncoordinated efforts where different agencies develop and implement IT solutions according to their sector-specific needs, without consideration for interoperability and information exchange with solutions used by collaborating agencies [7, 8]. The result is a fragmented landscape of different solutions that lack functionality for seamless sharing of information. To address these challenges, this study reports from a research project that focuses on enhanced IS support for collaborative emergency management, to establish COPs and shared SA among multiple stakeholders and agencies involved in joint operations.

Based on extensive interaction with Norwegian emergency management practitioners, the paper presents identified needs and requirements for information systems support for collaborative emergency management. The requirements focus on three basic elements for shared situation awareness (SA) in inter-agency emergency response: terminology harmonization, map-based COPs, and support for evaluation and learning from incidents through replay functionality in a map interface. Building on core design principles for emergency management information systems [6], we have developed prototypes supporting these three areas and validated these with potential users. The requirements and prototypes presented may serve as a basis for further development of standardized IS support for inter-agency emergency operations.

2 Background

In this section, we first briefly present challenges related to fragmented technology support and the lack of interoperable IS for emergency management. We then present related work on COPs for inter-agency collaboration and briefly review the design principles suggested by Turoff et al. [6].

2.1 Needs for Interoperable IS in Emergency Management

Emergency management is an area in continuous expansion and change, involving increasing threats from terror attacks, natural disasters, pandemics, and warfare. Global warming has resulted in dry summers and an increase of wildfires – globally but also in geographical areas not previously affected, e.g., the Swedish forest fires in 2014 and 2018. The Covid-19 pandemic struck in early 2020 and we have a current global security threat. All of these events make the dilemmas of fragmentation of information technology and IS increasingly visible and urgent. Many countries have decentralized crisis management systems. Such arrangement has consequences in terms of various software systems in use and lack of inter-organizational data access which limits the efficient sharing of information during crises [7, 8]. For instance, an earlier study in Germany identified 170 different ICT systems in use for supporting crisis management [9]. Similarly, studies of Scandinavian emergency management practice have identified how a range of various digital map systems is currently used by first responder agencies (police, fire, health services), municipalities, government organizations, and volunteer organizations) [10]. This severely inhibits the possibilities for inter-agency collaboration in emergency response. Our study aims to contribute insight into how the needs, requirements, and design of IS support can be used to improve such collaboration in crisis management.

2.2 Common Operational Pictures and Situation Awareness

A COP is a display or a series of displays of relevant operational information from a situation, showing, e.g., position of units, infrastructure, weather information, events, and decisions. While the COP concept lacks a univocal definition, some recurring elements are significant: structure, representation, processes, and management [11]. A COP is often manifested as a geographical representation combined with a checklist that describes the characteristics of the response operation [4]. During the past decades, there has been a focus on the potential of map-based COPs to increase common SA since it can capture and visualize the dynamics of crises. It can thus both be used in the crisis response phase when actors and agencies share information and make joint decisions, as well as for evaluation and learning purposes. SA, in its turn, can be described as the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status [1]. It plays an important role in situations where the environment is complex, and the actors need to ascertain critical cues to determine which decisions to make.

While research points at opportunities, corresponding practice tends to progress slowly. For instance, the Swedish Civil Contingencies Agency (MSB) published a report in 2016 pointing out the need for shared information and COPs among the Swedish response organizations [12]. Similarly, the Norwegian Ministry of Justice and Public Defense [13] in a government white paper pointed to how different terminology in use by the different responders for depicting the same concepts represents a challenge for information sharing and shared situational understanding in emergency management.

As pointed to by McNeese et al. [11], COPs are typically developed from non-user-centric perspectives and are being defined in technological terms that are not necessarily in the best interests of users. They defined this as a critical research gap since "success results from representations and visualizations that are highly user-centric, rather than just computationally-convenient or designed strictly from a programmer's mindset" [11, p. 468]. The specific focus of our study is thus on eliciting needs and requirements for COPs and shared SA that originate from emergency management practitioners.

2.3 Design Principles for Emergency Management IS

The work by Murray Turoff and colleagues on design principles for what they term a Dynamic Emergency Response Management Information System (DERMIS) represents a seminal contribution in conceptualizing design requirements for IS support for EM [6]. Based on an analysis of the role and tasks of first responders and emergency management personnel, they present an extensive framework of design premises, design concepts, and design principles. From this framework, Table 1 presents six (out of eight) design principles that have been influential on the prototype services developed in this study and that we consider to be important for the development of any such service. The principles were selected based on their relevance to the first prototype versions and their focus on core functionality. The two remaining principles, referred to as "content as address" (i.e., forming ad hoc groups based on common content interests) and "psychological and sociological factors", will be focused in further development of the prototypes.

Table 1. Selected design principles for Emergency Management Information Systems (based on [6])

Design Principle	Description
System Directory	The system directory should provide a hierarchical structure for the data and information currently in the system
Information Source and Timeliness	All data brought into the system dealing with the ongoing emergency should be identified by its human or database source, by its time of occurrence, by its status, and by its location (where appropriate)
Open Multi-Directional Communication	The system should be viewed as an open and flat communication process among all those involved in reacting to the disaster
Up-to-Date Information and Data	Data that reaches a user and/or his/her interface device must be updated whenever it is viewed on the screen
Link Relevant Information and Data	An item of data and its semantic links to other data are treated as one unit of information that is simultaneously created or updated
Authority, Responsibility and Accountability	Authority in an emergency flows down to where the actions are taking place

These design principles are then referred to in Sect. 5 where we present the design prototypes developed in our project.

3 Methods

3.1 Data Collection and Analysis

The study is a part of the INSITU project (insitu.uia.no) funded by the Research Council of Norway, running from 2019 to 2022. The project was conducted in close cooperation with stakeholders from Norwegian authorities and emergency management organizations for requirements analysis, participatory design, and validation of project deliverables related to enhanced information systems support for collaborative emergency management.

The results reported in this study are based on a combination of several research methods. First, we collected and analyzed several types of documents, including national regulations, emergency plans and guidelines, government white papers, and reports from exercises and evaluations. The document analysis served both as a basis for developing the interview guides and as sources for complementary information, see further detail reported in [10, 14].

A total of 23 semi-structured interviews have been conducted with Norwegian emergency management stakeholders and system vendors, including the following roles: incident commanders from first responders (police and fire), emergency dispatchers from command-and-control centres, municipal emergency coordinators, and providers and developers of map services. The interviews focused on the following topics: current practice for collecting and sharing information; terminology resources in use and experienced challenges related to lack of terminology harmonization; existing use of map systems and current practice for sharing geospatial information with collaborating partners; and current practice for the technology-supported evaluation and learning from incidents. Most of the interviews were recorded and transcribed in full.

Further, we conducted a two-day workshop in autumn 2019 with 24 participants from 20 organizations. This included national directorates, authorities, and first responders, thus enabling a broad representation of stakeholders from the emergency management domain covering strategic, operational, and tactical levels. The focus of the workshop was, based on current practices and needs for improvement, to elicit requirements for information systems support for collaborative emergency management.

The workshop was organized in three main sessions. First, a group roundtable discussions and experience exchange on current practice for establishing COPs and common situational understanding and, second, brainstorming on the stakeholders' needs for improvement. The participants were divided into four smaller groups where the aim was to have representation from various stakeholders, emergency organizations, and different organizational levels in each group. The groups worked with four different themes relating to various aspects of the COP(s). The groups rotated to attend the presentation of each theme so that each group had a chance to provide feedback on the brainstorming results of the other groups. On the second day, we employed "World Café" - a design method drawing on various design principles requiring active participation of stakeholders and group dynamics [15]. A café-like atmosphere is manifested through the establishment of four small groups working at round tables about a topic guided by a moderator. The same four groups rotated into different tables to discuss the various themes. The data collected in the brainstorming phase served as input. The results were then shared in the larger group at the end of the workshop. The workshop outputs were requirements identified in relation to the thematic focus areas of the project. Extensive notes were taken from the different sessions by project members specifically assigned this role. Material developed by the groups (flip-over sheets, post-it notes) was also collected.

The interview transcripts and material from the workshop were analyzed together using thematic analysis [16], identifying current practice and needs as a basis for developing requirements specifications for the different focus areas of the project: terminology harmonization, map-based COPs, and support for evaluation and learning from incidents.

3.2 Design Approach

The need to actively involve end-users in systems development and to anchor design solutions and requirements in user needs has been known for decades, sometimes referred to as participatory design and related to a socio-technical view on information systems [17]. In later stages of the IS development process, this can be related to practical views on design theory [18] where it is used to explain the means-ends relationship as a practical and prescriptive causal mechanism to justify design components. The particular DERMIS design principles also reflect the socio-technical system view at a more theoretical level and is thus motivated by this more general view on information systems. According to the socio-technical system view an information system consists of organizations, personnel, methods, equipment, and technological artifacts intertwined in implementing the assignments [19]. The DERMIS design principles clearly include all these factors.

In this study, we actively involved the users in the two-day workshop, letting them interact with each other and identify common practices and needs relating to both system functionality (technology) and organizational support. We then sorted the needs, prioritized them, and linked them to systems requirements complemented with requirements descriptions as is common in requirements engineering [20]. Where relevant, our requirements were also linked to basic design principles for emergency management information systems [6].

4 User Needs and Requirements

In this section, we present the empirical results in terms of the identified user needs and resulting core requirements for collaborative EM support related to terminology harmonization, map-based COP, and support for evaluation and learning from incidents.

4.1 Terminology Harmonization

Currently, terminologies for crisis management are fragmented and not maintained in a single repository, according to the respondents in the workshop. The Handbook for the Norwegian Rescue Services published in 2018 contains definitions of terms and acronyms to be used across sectors, but this is not exhaustive in terms of emergency scenarios covered and actors involved. The respondents expressed their needs for harmonization of terms used in large-scale emergencies involving collaboration between different sectors and levels in the respective organizations. Requests here, among other things concerned joint locations, repositories, overviews, consolidated lists. Common needs and related requirements are listed in Table 2.

Table 2. Needs and Requirements for Terminology Harmonization

Needs	Requirement Description
Easy access to joint use of terminology	Support for seamless and simple ways to access terms and symbols for joint use in training and practice
National online location of terminology support	The system should include a national authoritative online joint location for the terminology and search service
Joint terminology repository	The system shall provide a terminology repository for emergency map services including terminologies, glossaries, and dictionaries
Feedback channel	The system should include a simple feedback channel for comments from the users
Overview of properties of terms	The system shall include an overview of the properties of terms for harmonization, e.g., orthography or sound for audio communications
Consolidated list	The system shall include a consolidated list of sources of terminologies and symbols
Automated support	The system should provide automated support for collection and verification of sources to assure that the source owners can continue to maintain their sources

4.2 Map-Based COP

The analysis of current practices documented a need for common map support for a COP in larger emergency scenarios involving inter-sectoral collaboration. At the organizational level, the stakeholders requested a national-level standard for sharing information and the importance of having a joint repository for all Norwegian emergency map services and a standardized template with map overlays. Related to this, they also expressed a need for a common symbolization and a standardized usage of map symbols.

Regarding technology support, several of the respondents pointed to the need for sharing the same map-based COP interface across different agencies and to be able to transfer data or images, resources, and events in real-time. The map solution should be intuitive and made available as a unified system both internally and externally. Further, the respondents stated a need for visualization in terms of a map or a graphic representing both static information (e.g., critical infrastructure) and thematic layers supporting dynamic and situation-specific information such as weather forecasts, resources, and movement of personnel. Having a complete resource overview across agencies and organizations was here considered to be useful. At the same time, it should be possible to adapt the map displays to each stakeholder's needs, to avoid maps being 'cluttered'. One must also consider possible security issues resulting from the aggregation of different information elements that become sensitive when combined, such as the location of communications infrastructure. The main needs and corresponding requirements for map support are condensed in Table 3.

Table 3. Needs and Requirements for Map-Based COP

Need	Requirement description
National standards for sharing of map-based information	The map support shall be based on a national level standard for providing and sharing information, for multi-agency data access. It should provide dynamic integration of real-time geographic content across various emergency responders
Joint map repository	The map support shall provide a joint repository of thematic maps available in Norwegian emergency management, available as web map services
Common operation symbology	The map support shall include a repository of common operation cartographic symbols along with the standards of their usage
Overview and adaption	The map support shall provide overviews and layers with reduced content to be used in simplified operational map interfaces for various stakeholders
Rules to prevent information overload	The map support shall include rules for reducing information to be shown in a single map-based interface to prevent visual clutter and information overload

4.3 Learning from Incidents and Evaluation

As for evaluation and learning from incidents, the respondents in the workshop suggested that the COP should provide *"fact-based"* and *"objective"* information. It was also deemed important that the information provided is dynamic, with time scales, time logs and stamps, and continuously updated COPs that monitor the crisis development, to be able to reconstruct events and do systematic follow-ups. Some respondents also requested a decision repository and a COP with the capability to aggregate reports, generate action plans from reports, and extract statistical data. Further, the need for joint, inter-organizational after-action-reviews, vertical and horizontal evaluations at the management and/or operational level, and evaluations across sectors was recurrently pointed out. At the structural level, the respondents requested simplified national guidelines including support to develop concepts and training courses for evaluation, to develop common and regular routines for evaluations, to focus more on best practices, and to develop standards for evaluation, and regulations of how information should be stored, owned, and distributed. Some respondents also requested similar evaluation methodologies across organizations for synergy effects. Table 4 summarizes the identified needs and corresponding requirements for supporting evaluations and learning from incidents.

Table 4. Needs and Requirements for Evaluation and Learning from Incidents

Need	Requirement description
Fact-based, objective evaluation	The system should support objective and fact-based evaluation based on time stamps, maps, logs, and symbols, including descriptions of what facts users can access in the COP solution
Repository of evaluations and stakeholders	The system should include a repository that collects actors and agencies relevant to emergency management and systemizes them horizontally and vertically, to be accessible for cross-agency evaluations
Replay of incident timeline	The system should collect and present digital, dynamic, and aggregated information, replay events according to the timeline, and have updating functions for time stamps, maps, logs, and symbols
Repository for decisions	The system should store decisions taken during an exercise or operation for re-construction of the decision-making process
Repository for lessons identified	The system should store best practices, lessons identified and outcomes of previous evaluations

5 Development of Prototype Services

Based on the collected user needs and requirements, our research project has designed and developed prototype services for terminology harmonization, map-based COP for inter-agency collaboration, and support for evaluation and learning. This section briefly presents these prototypes.

5.1 Prototype for Terminology Harmonization

Considering terminology harmonization, a central requirement was that the COP should include a joint repository including glossaries and harmonized terms providing translations when first responders from several sectors may have a different understanding of terms and concepts. In the design phase, this was addressed by proposing a way to apply the Norwegian Public Management Standard for concept harmonization or concept differentiation to existing glossaries in crisis management. Also, supporting actions for harmonization and introducing aspects of oral and written communication related to similarities of sounds and meaning, were suggested. In total, concepts from around thirty terminology sources (Norway, EU, UN) covering Norwegian or English concepts were collected. Some of these sources cover many language combinations, including the General Multilingual Environmental Thesaurus (GEMET), with over five hundred combinations each. This is integrated into an online resource, TERMER, where stakeholders can search across the word lists from the national rescue handbook, and all the known sector-specific sources to facilitate further harmonization. The online resource also includes a feedback functionality so that users can comment on both existing and missing concepts. This reflects Turoff et al.'s [6] design principle of *Authority, Responsibility and Accountability* (See Table 1), as the glossary is intended to be coordinated at national level while being interactively accessible to the emergency organizations.

The TERMER online terminology resource can be installed on the emergency organizations' web page, then supporting terminology search on all contents of the pages including pdf documents. This is in line with the design principle to *Link Relevant Information and Data* [6] (see Table 1). According to this principle, a data item and its semantic links to other data are treated as one unit of information that is simultaneously created or updated. Figure 1 shows an example of the installation of TERMER on the web page of the Norwegian Joint Rescue Coordination Centre (JRCC) (www.hovedredningssentralen.no).

5.2 Design of Map-Based COPs for Collaborative Emergency Management

The stakeholders expressed a basic need for a national standard and service for emergency-related maps. While the Norwegian Directorate for Civil Protection (DSB) offers a map service with thematic layers related to different emergency scenarios and resources (e.g., forest fire), this is not in widespread use among emergency stakeholders and is also not well known. This is partly because the system is not intuitive in use with a complex user interface, and also because the technology on which the system is based now appears somewhat outdated. There is currently a national initiative on establishing a digital map repository that can also support emergency management, led by the Norwegian Mapping Authority. However, this process seems rather slow and is still at the planning stage. The project, therefore, designed a 'lightweight' and easy-to-use application for map-based information sharing supporting collaborative emergency management, which can be used on different devices (laptop, iPad, mobile phone).

Figure 2 shows a screenshot of the application. The system includes functionality where the organization in charge of the emergency response can create an event in the system and then invite collaborating stakeholders/agencies at different organizational

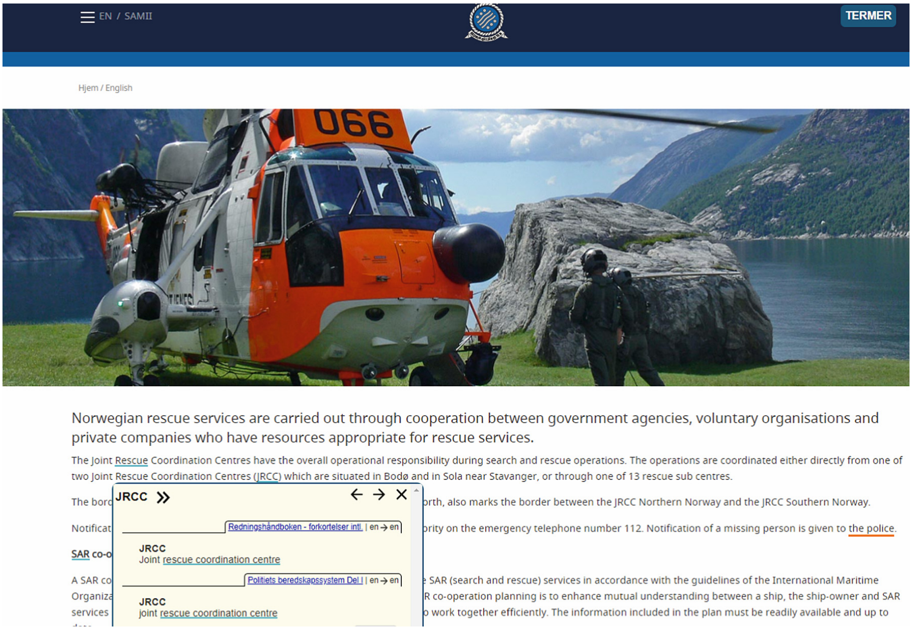

Fig. 1. Screenshot from use of the TERMER application at the JRCC web page

levels (tactical, operational, strategic) to share information in the same map interface. This reflects the design principle of *Authority, Responsibility and Accountability* [6] (ref. Table 1) according to which there needs to be clear accountability of who is taking what actions. Each user can create, for instance, an event or point of interest (POI) and place symbols, the position of units, on the map. The example in Fig. 2 depicts a safe zone for a traffic accident with hazardous material. A simplified situation report can also be generated, based on the actions performed by the users. As to requirements for information sharing, a chat function is also included to enable the stakeholders to quickly communicate their actions and share information with each other. It is possible to filter information depending on whom you want to share information with (all or selected actors) and whether or not information can be shared with the media.

The functionality of this application reflects the design principle of *Up-to-date Information and Data*, according to which data from the emergency system that reaches a user and/or their interface device must be up-to-date, whenever it is viewed on the screen [6]. Further, it also reflects the design principle of *Open Multi-Directional Communication*, according to which any emergency management system should be viewed as an open and flat communication process among all those involved in reacting to the disaster (ibid.).

As to the need for common map symbols, GIS experts in our project team collected and analyzed official emergency map symbol repositories in use by different emergency responders and system vendors in Norway. They then extended the symbol set, symbol modification, and grouping of symbols. Symbols could relate to info-types such as electricity, water, waste, weather, crimes, operations, activities, and statistics. Concepts of symbol standardization and harmonization were also proposed, all reflecting

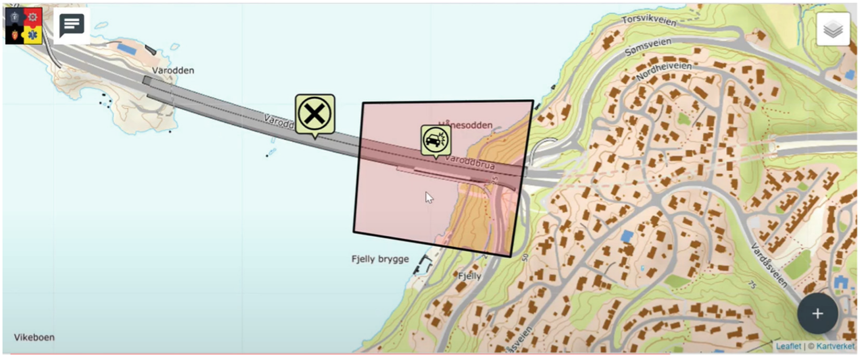

Fig. 2. Screenshot of the map-based information sharing tool

requirements of standardization and joint symbols [21]. The use of thematic layers at the strategic, tactical, and operational levels also reflects the design principle of a *System Directory* [6]. According to this principle, the system directory should provide a hierarchical structure for all the data and information currently in the system.

5.3 Prototype for Supporting Evaluation and Learning

As to evaluation, we chose to focus on the requirements for replaying incidents to enable objective, fact-based evaluations as this was jointly stated among the stakeholders participating in the requirement workshop. In the prototype for map-based information sharing, we thus also included a replay function for information sharing, chat communication, and decisions taken during the incident, displayed at various speeds based on a timeline indicator. It is also possible to freeze the timeline and take screenshots if you want to explore something in more detail. When a user replays the event, it is possible to register evaluation notes (e.g., something went wrong here, why?) that can be used in later evaluations, thus reflecting the requirement of a repository of lessons learned. The replay function is displayed in Fig. 3, reflecting the design principle of *Up-to-date Information and Data* [6].

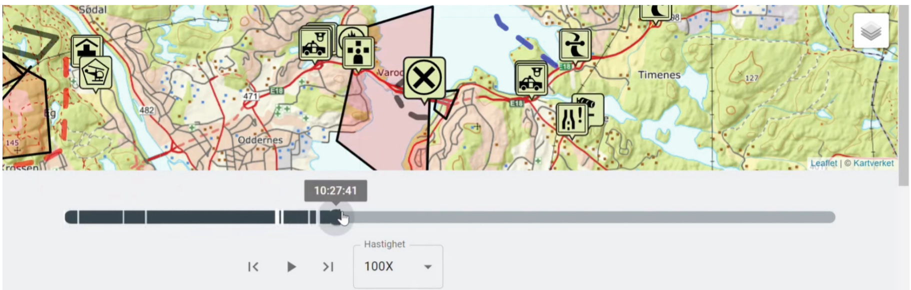

Fig. 3. Replay function in the map-based evaluation tool

6 Discussion

In this section, we reflect on the results of our project this far, considering extant related research. We also briefly discuss associated implementation challenges and transferability of the study results.

6.1 Improving Inter-agency Collaboration with Map-Based COPs

As stated in the study introduction, the need for joint crisis management operations and inter-agency collaboration is substantial and will likely increase in the future. COPs for improved common SA are certainly no new phenomenon but technological advancements have provided new opportunities, e.g., in terms of map-based COPs with real-time information updates. In this context, former research has provided important contributions in the form of concepts, architectures, and tools for supporting situation awareness and COP [2–4]. Yet, as described previously, the landscape is still fragmented with individual response organizations and agencies developing their own solutions without focusing on interoperability and supporting collaborative operations.

Also internationally, there is a lack of universal solutions supporting a COP. The International Forum to Advance First Responder Innovation [22] points out that there is a major gap in first responders' ability to collect data from traditional (e.g., weather maps, sensor readings) and nontraditional (e.g., social media) information sources, and to integrate this data into a user-configurable COP. It has also been pointed out, that even with access to a shared COP space, this may still result in multiple interpretations and a lack of a common SA among the actors involved [5].

The requirements elicited in our study and the resulting prototypes are intended to contribute to progress further in establishing systems support for COPs adapted to the need of the different emergency stakeholders. The identified needs and requirements are both technical and organizational and thus in line with the socio-technical system view [19]. However, as discussed in the next section, for these requirements and prototypes to be taken further requires addressing implementation challenges concerning organizational resources, training, and even legislation related to data privacy and secrecy.

6.2 Stakeholder Involvement in Design and Evaluation of Emergency Management Systems

The need to involve stakeholders is crucial in any IS development process [20] and perhaps even more so in emergency management. This is because solutions that are not solidly based on user needs may have fatal consequences. Our study is based on principles of active user participation in combination with the socio-technical system view, [19] and design principles applied to emergency systems [6]. This should be seen as a major contribution of the study, i.e., that it presents extensive requirements for collaborative emergency management support as stated by the involved stakeholders and based on these developing prototypes in an application domain where technology development often is fragmented and non-user-centric [11].

The stakeholders have also been involved in further validation of the design proposals and prototypes, including focus group interviews and exercises. In a digital table-top exercise in spring 2021 using a forest fire scenario, we studied how access to a common map system could possibly support shared situation awareness among emergency stakeholders at the local, regional, and national levels. The exercise involved eighty participants from the fire services in three municipalities, the police, the county's emergency management, municipal emergency managers, GIS experts at national and local levels, the public road authority, and critical infrastructure operators. While illustrating the potential for improved inter-agency SA through a map-based COP, the exercise also documented the need for developing more specific information sharing procedures for use of this service to be effective across the tactical, operational, and strategic levels of the emergency response. Another table-top exercise took place in spring 2022, involving 8 stakeholders from various agencies and response organizations and focusing on the information sharing and replay function. The results from this exercise served to validate how the replay functionality as implemented in our prototype could contribute to the more systematic evaluation and learning from incidents.

As clearly illustrated in the results of this study, besides addressing the technological and functional requirements there are also several requirements at the organizational, inter-agency, and structural levels that could be more challenging to solve. As the stakeholders pointed to, supporting the need for common systems for map-based COP requires coordination at the national level, also providing the required funding and personnel resources for development and maintenance. As mentioned in Sect. 4.2, this overall support is further related to concrete needs for sharing the same map-based COP interface across different agencies and transfer information in real-time. How this is done, i.e., establishing a control mechanism, must likely be worked out together with the command-and-control center, which is typically established for an emergency and where all agencies have representatives. Also, considering the security issues relating to aggregation of information elements, additional design principles such as "securing classified information or having a system to control user access to classified information" must likely be integrated in mature protypes and real implementations.

In relation to the above, different areas in our suggested solution concept may have different prospects of being implemented. For instance, as to terminology harmonization, the TERMER online resource is developed by a private company that is a project partner specializing in terminology services and thus may have a good possibility for turning the prototype into a commercial product. While the replay function for evaluation is much dependent on organizational and national structural support, the function must be accompanied by training, after-action-review processes, and processes for (inter-) organizational knowledge transfer, if it is to enable best practice and double-loop learning [14].

Finally, a basic design premise formulated by Turoff et al. is also relevant to bring into focus here: "An emergency system that is not used on a regular basis before an emergency will never be of use in an actual emergency" [6, p. 6]. In line with this, the prototype services developed in our project can also be used to support work practices of emergency management professionals outside emergency situations, related to joint terminology (e.g., in preparedness planning) and map-based information sharing in training and exercises.

7 Conclusion

In the study reported in this article, we have collected and analyzed needs and requirements from emergency stakeholders in various sectors and organizational levels and facilitated interaction among these in a requirements elicitation workshop. Based on this we have developed prototype applications supporting terminology harmonization, common map symbols, map-based support for information sharing and COP, and support for objective and fact-based evaluation and learning from incidents through the replay of actions in the map-based COP. The requirements and prototypes have been further validated by stakeholders and prospective users in focus group interviews, workshops, and exercises.

Recent technological developments have enhanced the possibilities to produce and enhance map-based development, representations, and visualization of COP functionality. As illustrated in our study, this enables the development of systems support that addresses essential design principles for emergency management information systems as defined by Turoff et al. [6]. The study thus also documents the continued importance of these design principles presented nearly two decades ago.

Our study contributes with a user-centric approach in identifying comprehensive requirements for IS support for collaborative emergency managers together with stakeholders, moving from needs to requirements to design proposals and covering core elements of COPs needed for improved joint SA. The collected requirements and prototypes developed may serve as a basis for further development of standardized solutions. As presented earlier in the paper, the TERMER resource is already implemented by the Norwegian Joint Rescue Coordination Centre, and the Norwegian Directorate for Civil Protection (DSB) has expressed interest in using the map service developed in our project as a demonstrator in the process of further design and development of a national system for emergency map support.

While the context of this study is limited to emergency management practice in Norway, the requirements for the COPs for cross-sectoral collaboration are considered to have broader relevance to researchers and practitioners in the emergency management domain. Thus, since the need for inter-agency collaboration will likely increase in the future and basic needs for information retrieval, sharing, improved SA, and evaluation are similar across national contexts. However, the prototyped functions have been developed for a decentralized emergency management system and may thus be most relevant to similar organizational structures. Future work should also focus more on challenges to organizational implementation of the support systems that need to be addressed for diffusing these solutions in the community of emergency management stakeholders. This work could build further on design principles from Turoff et al. [6] related to psychological and sociological factors, as well as extending these with new design principles relating to system security.

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References

1. Endsley, M.R.: Toward a theory of situation awareness in dynamic systems. Hum. Factors **37**(1), 32–64 (1995)
2. Luokkala, P., Nikander, J., Korpi, J., Virrantaus, K., Torkki, P.: Developing a concept of a context-aware common operational picture. Saf. Sci. **93**, 277–295 (2017)
3. Van Dijk, H.: Situation awareness in crisis situations: development of a user-defined operational picture. In: Proceedings of the 12th International ISCRAM Conference, Kristiansand, Norway (2015)
4. Wolbers, J., Boersma, K.: The common operational picture as collective sensemaking. J. Contingencies Crisis Manag. **21**(4), 186–199 (2013)
5. Steen-Tveit, K., Munkvold, B.E.: From common operational picture to common situational understanding: an analysis based on practitioner perspectives. Saf. Sci. **142**, 105381 (2021)
6. Turoff, M., Chumer, M., Van de Walle, B., Yao, X.: The design of a dynamic emergency response management information system (DERMIS). J. Inf. Technol. Theory Appl. (JITTA) **5**(4), 1–35 (2004)
7. Grottenberg, L., Njå, O.: Applying a systems safety approach to the development of GIS in the Norwegian emergency management domain. In: Cepin, M., Bris, R. (eds.) Safety and Reliability. Theory and Applications, pp. 484–491. CRC Press (2017)
8. Meum, T., Munkvold, B.E.: Information infrastructure for crisis response coordination: a study of local emergency management in Norwegian municipalities. In: Proceedings of the 10th International ISCRAM Conference, Baden-Baden, Germany, pp. 84–88 (2013)
9. Neuhaus, C., Giebel, D., Hannappel, M., Färfers, S.: Crisis management systems in Germany - a status report about the current functions and developments of private and public crisis management systems in Germany. In: Proceedings of the 9th International ISCRAM Conference, Vancouver, Canada (2012)
10. Opach, T., Rød, J.K., Munkvold, B.E., Radianti, J., Steen-Tveit, K., Grottenberg, L.O.: Map-based interfaces for common operational picture. In: Proceedings of the 17th International ISCRAM Conference, Blacksburg, VA, USA, pp. 506–516 (2020)
11. McNeese, M.D., Pfaff, M.S., Connors, E.S., Obieta, J.F., Terrell, I.S., Friedenberg, M.A.: Multiple vantage points of the common operational picture: supporting international teamwork. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. SAGE Publications, Los Angeles, CA (2016)
12. Landgren, J., Borglund, E.: Att skapa och analysera lägesbilder vid samhällsstörningar. Swedish Civil Contingencies Agency (MSB) (2016)
13. Meld.St.10: Risk in a Safe and Secure Society. Norwegian Ministry of Justice and Public Security (2016–2017)
14. Pilemalm, S., Radianti, J., Munkvold, B.E., Majchrzak, T.A., Steen-Tveit, K.: Turning common operational picture data into double-loop learning from crises - can vision meet reality? In: Proceedings of the 18th International ISCRAM Conference, Blacksburg, VA, USA (2021)
15. Nunez, H.C., Rybels, S., Coppens, T., Valderrama Pineda, A.F.: World café as a participatory approach to facilitate the implementation process of problem-based learning. J. Probl. Based Learn. High. Educ. **8**(1), 19–40 (2020)
16. Bowen, G.A.: Document analysis as a qualitative research method. Qual. Res. J. **9**(2), 27–40 (2009)

17. Schuler, D., Namioka, A.: Participatory Design: Principles and Practices. CRC Press (1993)
18. Markus, M.L., Majchrzak, A., Gasser, L.: A design theory for systems that support emergent knowledge processes. MIS Q. **26**(3), 179–212 (2002)
19. Orlikowski, W.J., Iacono, C.S.: Research commentary: desperately seeking the "IT" in IT research - a call to theorizing the IT artifact. Inf. Syst. Res. **12**(2), 121–134 (2001)
20. Aveson, D., Fitzgerald, G.: Methodologies for developing information systems: a historical perspective. In: Avison, D., Elliot, S., Krogstie, J., Pries-Heje, J. (eds.) IFIP WCC TC8 2006. IFIP International Federation for Information Processing, vol. 214, pp. 27–38. Springer, Boston (2006). https://doi.org/10.1007/978-0-387-34732-5_3
21. Opach, T., Rød, J.K.: A user-centric optimization of emergency map symbols to facilitate common operational picture. Cartogr. Geogr. Inf. Sci. **49**(2), 134–153 (2021)
22. IFAFRI: Capability Gap 4 "Deep Dive" Analysis Synopsis. The International Forum to Advance First Responder Innovation (2018)