Managing natural hazards in Sweden – needs for improved information and decision support systems

Viktor Sköld Gustafsson
Linköping University
viktor.skold.gustafsson@liu.se

Tobias Andersson Granberg
Linköping University
tobias.andersson.granberg@liu.se

Sofie Pilemalm
Linköping University/University of Agder
sofie.pilemalm@liu.se

Martin Waldemarsson
Linköping University
martin.waldemarsson@liu.se

ABSTRACT

This paper explores opportunities for information systems to support emergency response to multiple natural hazards. Interviews were conducted with 12 representatives from actors of the Swedish emergency response system about response to multiple natural hazards. Challenges and needs connected to five themes influencing the response effort were identified: Cooperation, Resource management, Command and control, Common operational picture, and Risk management. The results illuminate a lack of technology to support decisions and analyses during emergency response to both single and multiple natural hazards. Based on this, the paper suggests and discusses information systems and decision support tools to assist in satisfying the identified needs. The findings can inform policy makers in emergency response of where to concentrate the development of collaborative preparedness and response work, and the scientific community of future research directions.

Keywords

Emergency response, extreme weather events, command and control, needs analysis

INTRODUCTION

Climate change with an increase of the global mean temperature by 1°C or more, will likely lead to glacial melt and disruptions in the global ocean streams (IPCC, 2014). Other phenomena include increased frequency of extreme weather events, leading to higher risks of additional natural hazards, e.g., landslides and forest fires. Such a chain of events can be called multiple natural events (Gill and Malamud, 2014), where a primal natural event directly triggers or, by changing the environment, increases the probability of secondary events. The increased risk of multiple natural events brings challenges to the planning and decision making in emergency response (ER) systems, especially in areas with limited experience from this, e.g., Sweden and other Scandinavian countries. Sweden has, like many countries, a decentralized ER system with no single national agency responsible for overall emergency management (EM). Instead, most responsibility is put on the municipalities. To coordinate a single large crisis with many involved actors is difficult, not the least in a decentralized crisis management structure (Grottenberg and Njå, 2017). With the current lack of joint information and decision support systems, multiple natural hazards will be even more challenging in terms of command, control, and coordination of the responses, which can have devastating consequences. At the same time, contemporary studies on technologies for handling multiple hazards (e.g., Damalas et al., 2018), do not seem to be based in the needs of practitioners. This calls for an exploration of the current EM to increase the understanding of factors that influence the response to multiple natural hazards, and how information systems can help to improve this.

Aim and objectives

This paper adds to the understanding of factors influencing Swedish emergency response to both single and multiple natural hazards. The aim is to identify needs for improved information and decision support systems to enhance Swedish emergency management. The objective is to provide new directions of research and important insights for policy makers concerning how to manage future extreme weather events.

Related work

While there are previous studies developing information systems and decision support to improve ER to *multiple* natural hazards (e.g., Damalas et al., 2018; Su et al., 2016), there is a lack of studies on the actual needs from the ER systems to manage these types of events. This creates a gap between the scientific community and the practitioners of EM. However, several studies examine issues, needs, and challenges of ERs to large-scale *single* natural hazards, and some provide suggestions or directions for improvements connected to information systems. According to Bosomworth et al. (2017), two core challenges to strategic EM in Australia are community expectations, and effective use of information systems and social media. They suggested that to overcome the challenges, EM needs to be a component in community disaster risk reduction and a network governance approach should be adopted for comprehensive cooperation and easier dissemination of information. In a retrospect analysis of four disasters in Asia and the U.S., Miao et al. (2013) identified typical issues of emergency resource management: inefficient communication and a lack of interaction, cooperation, and integration. They also suggest a more holistic approach with comprehensive information systems and cross-network integration of information platforms, for reliable and effective information sharing. Comprehensive EM should cover all phases of the EM cycle (Greiving et al. 2006; Motamedi et al., 2009), and be combined with planning and operation systems (Pesigan and Geroy, 2009).

Another challenge identified in the literature is public awareness, both regarding the risk of hazards and the subsequent ER. According to Tingsanchali (2012), who studied EM for urban floods in Thailand, public awareness can be increased by community participation in risk assessments and planning of flood hazards. The involvement of communities and social organizations can be crucial in the management of natural hazards (Sim and Yu, 2018), as they often constitute a first response and is a main actor for local resilience (Genovese and Przyluski, 2013). A participatory process will also increase the success and effectiveness of warning systems and communication with the public, by increasing the public's knowledge of risks and make them more familiar with natural hazard responses (Bird et al., 2018; Tingsanchali, 2012). Bird et al. (2018) identified several success factors of interactive crisis communication during the Eyjafjallajökull eruption in Iceland, e.g., pre-eruption town hall meetings, the establishment of information and media centers, and increased dissemination of risk data. More complex natural hazards in the future will also require more creative responses, which need to be accepted by the public through improved interactive public communication (Steelman and McCaffrey, 2013).

Theodora (2020) suggest that natural hazards also require the integration of advanced digital technology to support information gathering, evaluations, prioritization, visualization, and monitoring. According to Simonovic et al. (2021), new technology needs to consider complex multi-hazards, and decision tools based solely on risk are insufficient. They suggest a holistic approach, considering the larger societal system affected by the hazards, all costs and benefits, and alternative solutions, with tools based on multi-objective optimization and simulation. A challenge for all technological systems is the user acceptance, which Lu and Xue (2016) identified as an obstacle for joint sense-making between response actors in China, a crucial aspect for responses to large-scale emergencies.

The contribution of this paper is to address the research gap on identifying the actual needs of ER systems when managing multiple natural hazards. Since Sweden has limited experience of such events, we address this gap by studying the current ER system and how it would function during multiple natural hazards.

Study context

The Swedish ER system is decentralized, with the main responsibility of response put on the *affected* (individual or organization), the *municipalities* and the *county administrations* (CA). The actors involved in the response to natural hazards can be divided into three groups: response actors, support actors, and expert actors.

The main response actors are the *fire and rescue services* (FRS), handling fires and accidents, and the *emergency medical services* (EMS), providing aid to injured people. The FRSs are organized on municipal level or in larger federations covering multiple municipalities, while the EMS are organized on the county level with the ambulance service sometimes procured from contractors. Depending on the circumstances, they can have support from voluntary response organizations, the Swedish Armed Forces, the Swedish Police, and private contractors.

The supporting actors include the *municipalities*, which should work for cooperation and coordination between societal actors during an extraordinary event, e.g., a natural hazard. The municipality is also responsible for providing information to the public. The CA also have similar responsibility on a regional level, concerning the coordination and cooperation between several municipalities. The *Swedish Civil Contingencies Agency* (MSB) can provide support to responding FRS organizations in terms of resources and coordination. Other supporting agencies that may be involved during natural hazards are the *Swedish Public Safety Answering Point* (PSAP), the *Swedish Church*, *business actors*, and *voluntary support organizations*.

Several expert actors can assist the response actors with information concerning different natural events. For instance, the *Swedish Meteorological and Hydrological Institute* (SMHI) is one of the main expert actors, forecasting all weather-related events, monitoring all larger watercourses, and providing information about the current wildfire risk through the Fire Weather Index (FWI). The *Swedish Geotechnical Institute* (SGI) has the role to inform and support other actors concerning geological hazards, e.g., landslides or debris flows. If a natural hazard has impact on critical infrastructure, e.g., the road or rail network, the *Swedish Transport Administration* will be involved to support the response with information and knowledge.

METHOD

In total, 10 semi-structured interviews with different actors of the Swedish ER system were conducted March 2020 - June 2021. The interviewees are presented in Table 1. Semi-structured interviews were chosen to enable flexibility and the opportunity for follow-up questions. An interview guide was established with open-ended questions regarding the ER to multiple natural hazards, e.g., which actors that are involved in the response, what they do, and the challenges or factors influencing the response given the specific characteristics of the scenarios.

The interview with the PSAP was a group interview with three interviewees, while the others were individual interviews. The recruitment of participants was mostly done through a mix of strategic selection and snowball sampling as described by King et al. (2019). Although there is a risk of bias applying snowball sampling, it was needed due to the low experience of multiple natural hazards in Sweden.

Table 1. Interviewee information.

Interviewee	Interview	Role	Affiliation
Interviewee 1	1	Project leader & administrator	MSB
Interviewee 2	2	Operative manager	FRS
Interviewee 3	3	Fmr. Federation president	FRS
Interviewee 4	4	Operative manager	FRS
Interviewee 5	5	Preparedness coordinator	Municipality
Interviewee 6	6	Application specialist	PSAP SOS Alarm
Interviewee 7	6	Preparedness administrator	PSAP SOS Alarm
Interviewee 8	6	Preparedness administrator	PSAP SOS Alarm
Interviewee 9	7	Mitigation & preparedness manager	FRS
Interviewee 10	8	Communication & security manager	Municipality
Interviewee 11	9	Rescue chief	FRS
Interviewee 12	10	Preparedness administrator	CA

All interviews were held remotely via the meeting applications Zoom or Microsoft Teams. Remote interviews were chosen primarily because of the Covid-19 pandemic. In all interview sessions two researchers were present, one leading the interview and the other taking notes in terms of interpretations of the interviewee's answer and other reflections of the interview. All interviews were audio recorded.

In a thematic analysis (Saldaña, 2013), an initial round of preparatory holistic coding was done by listening through each recording and code with a short phrase to get a grasp of the content and meaning of a longer sequence. Using a mix between descriptive and process coding methods, more refined codes describing aspects and actions connected to the response were achieved. These were grouped and categorized according to similarities and superordinate themes were established, grouping similar second cycle codes in what could be called "categories of categories" (Saldaña, 2013) .

RESULT AND ANALYSIS

In the following section, the results of the study are presented in the themes *Cooperation*, *Resource management, Command and control*, *Common operational picture*, and *Risk management*. Each theme is followed by identified needs and suggested solutions to improve some aspects connected to the theme.

Cooperation

ER in Sweden include a great deal of cooperation between different actors and hierarchical levels. At local level, the cooperation involves intra-municipal actors, often with the FRS or the municipality as initiator. Between the FRS and the municipality, we have identified two main cooperation areas: information and resources. For some natural hazards, especially cloudburst or river-flow triggered floods, the municipality can support the FRS with preventive or sanitary work by providing their resources at the FRS's disposal. The municipality also have cooperation between its own departments, e.g., technology and exploitation, to work proactively against natural hazards. Moreover, the interviews shows that the FRS cooperates with contractors for support with preventive measures, e.g., digging support channels during flood risks, or preventive behavior, e.g., avoiding forestry and groundwork during high risk of wildfires. Post-event cooperation with landowners is important since they have the responsibility for the event when it is no longer classified as an emergency.

Most counties in Sweden have a predefined regional cooperation between ER actors, especially the CA, the municipalities, and the FRSs. Furthermore, several larger water courses have a fixed cooperation plan between actors along the river, including the CA(s), the municipalities, power companies operating in the river, and the FRSs. They cooperate on matters like, e.g., water depletion, public communication, and common operational pictures (COP). County cooperation can be escalated by the CA(s) during large emergencies, who invites relevant expert actors. Overall, the regional cooperation has a flexible structure, where the level and size depend on the incident.

Usually, regional cooperation is facilitated through a cooperation conference initiated by any public actor in the response system. The request is communicated to the PSAP, who invites participants determined by the initiator. In general, a conference is initiated when several municipalities are affected. For certain events, some counties have a fixed point in time when a conference should be initiated, for example when river flows reach class 2. For other events, e.g., drier conditions with wildfire risk, there may be preparation meetings between a few actors, often FRSs, for information sharing and discussion. A regular county cooperation conference will be initiated first when one or several fires start. The conference should establish a COP and decide upon necessary measures, which requires information sharing between actors. The CA often assumes the role as information hub for dissemination between involved actors.

Several interviewees brought up regional cooperation between FRSs, often regarding the use of resources or joint command and control (C2). This type of cooperation seems to be a necessity for the Swedish ER system to function and is also identified as the most developed. Another approach identified was the use of cooperation officers representing groups of FRSs. One interviewee mentioned that their county was divided into subareas, with a corresponding cooperation officer representing all FRSs in the same area, for smoother communication between the FRSs. We also identified rationalizations between FRSs, where one filled and provided barrier sandbags to others during risk of river floods.

Identified needs and support suggestions: systematic evaluation of response and cooperation

There are several examples of cooperation networks in several counties during the response to a natural event, however, one FRS representative raised the lack of coordination to follow-up and evaluate ER. FRSs are obligated to write response reports, which can be analyzed, tracked, and compared to the decisions taken during the response. However, there are currently no system or application that enable such follow-ups, partly because the response information is decentralized between different platforms.

Resource management

The main pool of human resources lies within the FRSs. Their personnel all have the same basic training, to respond to all types of emergencies, with potential special competences, e.g., high-altitude rescue missions. Most personnel in the FRS resource pools constitute full time, part time, and voluntary resources divided between different stations. During large natural hazards, the rescue chief can activate a full alarm on one or several stations. Then, part of, or all, off-duty fire fighters will respond. Hence, a lot of resources are hidden and not shown as available in the resource management systems.

Some FRSs reallocate equipment between stations during high risks of natural hazards. If the area near one station has an increased risk of high river flow or sea levels, it will be strengthened with equipment from other stations. However, during increased risk of wildfires, it is difficult to quantify a higher risk in one area over another, thus, the equipment is reallocated for equal preparedness. During larger natural events, FRSs may have a shortage of resources. Then, remaining resources are centralized and allocated to the most populated areas. Furthermore, reinforcement resources can be requested from other FRSs, other response agencies, volunteers, or from the national resource pool. There is also a possibility to receive aid from the Swedish Armed Forces, including both human resources and equipment.

An FRS may need response assistance at an ongoing natural event, or to maintain basic preparedness for other potential emergencies. Several of the interviewed FRS representatives mentioned agreements of border-less use of resources between two or more FRSs during shortages. Some FRSs have basic agreements to aid, while others have entered larger coordination clusters with unlimited access to each other's resources and a joint C2 center.

MSB is the broker of the national resource pools, where the three most relevant for natural hazards are: wildfire, flood, and aerial firefighting. The wildfire equipment is stored in 24 depots divided between 14 locations, while the flood equipment is placed at one location. Available aerial firefighting resources are helicopters and scooping airplanes, procured by MSB from contractors. However, the flying resources are only available during the standard fire season determined by MSB and SMHI. If several requests reach MSB, they will assess the national needs and decide how to allocate the resources to the counties and FRSs requesting them.

Identified needs and support suggestions: tools to support evaluation of national reinforcement needs

When MSB decides which actors to provide reinforcements to, they need to evaluate and compare the requests to identify which actors have most urgent need of the resources. We have not been able to identify any tools to support these decisions, although several FRS representatives interviewed demonstrate their trust towards the current evaluation.

Identified needs and support suggestions: cooperation platform for reinforcement identification and planning

Several interviewees mention that for FRS routine operations, the availability of emergency managers (rescue leaders, rescue chiefs) is a bottleneck. However, during larger events, general resource limits will also be reached and there will be a need for reinforcement resources to maintain the minimum preparedness. A shared platform between cooperating response actors that visualizes the resource availability can support decisions regarding when and from where reinforcements should be requested.

Command and control

During responses to natural hazards, the focus, coordination, and cooperation are based on response tactics set by the rescue commanders. From the interviews, there are more established tactics for wildfires compared to other natural hazards. One of them is called *increased resource deployment*, where the PSAP will deploy more FRS resources than normal to have a strong initial response during periods of high wildfire risk. It is also possible that the FRS requests assistance from flying reinforcements already at the drive-up to the incident, based on information in the emergency call. Another principle is to avoid unnecessary movements of firefighting units when the fire development changes. If possible, another unit will be deployed, combatting the fire from the suggested location. Since preventive fire breaks are uncommon in Sweden, the FRSs use natural ones, e.g., lakes, rivers, and roads.

During large events with rapid onsets and high resource demands, the FRS and PSAP can agree to *depart from standard deployment* procedures in a municipality. It means that the backend FRS operator will not listen in on calls and no resources will be deployed for non-life-threatening matters. Instead, the PSAP forwards these matters directly to the C2 center, where sorting and prioritization is done. This type of C2 is used for natural hazards like cloudbursts and storms, with a lot of calls to the PSAP and with limited amount of available FRS resources.

When managing natural hazards, response and support actors can activate a *state of alert* (SOA). The FRS can activate SOA on different hierarchical levels: at the emergency site, on local C2 level, and on regional federation C2 level. For larger events, the emergency site, led by the rescue leader or an appointed site leader, can be split into sectors led by an appointed sector leader, thus, one emergency site can consist of several C2 points. If the event affects several municipalities, involved FRSs may activate a shared SOA with a joint C2.

The CAs have different alert levels; on-duty official, reinforced on-duty official, and SOA. On-duty official is the standard alert level, with one available official for calls from response actors or other agencies. During large natural hazards, the level may be raised to reinforced on-duty official and more resources are assigned. If the situation in the county requires emergency management on top of the municipality and FRS, the county governor can decide to activate SOA. At this level, all relevant functions of the CA participate in the SOA board, to manage emergencies and to support the municipalities and FRSs. Furthermore, the CA has the mandate to take over the FRS of a municipality, if it is unable to cope with an incident. It means that the CA will be responsible for all FRS activities in the municipality and will establish a more robust C2. However, FRS takeovers are rare, and will only be performed if the situation is expected to last for a considerable time.

Identified needs and support suggestions: tools to identify aerial reinforcement needs

It is important to dispatch sufficient resources to limit the spread and prevent larger wildfires. One tactic to limit the fire is to use aerial firefighting resources, which in Sweden consists of contracted planes and helicopters. A tool that identifies these needs during wildfires can potentially lead to a faster limitation of ongoing wildfires.

Identified needs and support suggestions: enable backend support from other organizations

The main reason for FRS takeovers is the lack of C2 capability in the ordinary organization. An alternative could be to enable backend support from another FRS organizations with a stronger C2 center. However, this is only possible with compatible information systems, enabling cross-system communication and information flows.

Identified needs and support suggestions: shared SOA between actors

According to several interviewees, the capability of shared SOA between different actors need to increase to improve the ER to large-scale events. However, one municipal representative raised the fact that actors seldom share facilities, which hinders a shared SOA. One way to overcome the location obstacle is to enable a digital version of shared SOA, offering ways to cooperate without being in the same C2 center.

Common operational picture

Before and during responses to natural hazards, information is gathered and shared between actors to support the establishment of a COP. The COP is crucial for efficient cooperation, and all interviewees mentioned it recurrently.

The information gathered during responses to natural hazards stretches from picking up information in the emergency calls to counselling with experts. This includes data from forecasts, surveillance, monitoring and simulations. The FRS try to seek information from different kinds of experts: event specialists from agencies (e.g., SMHI, SGI, CA), experts on the specific operations affected (e.g., business actors), and experts on the hazard surroundings (e.g., landowners). Several of the FRS representatives thought this type of information was extremely valuable during a response, although difficult to gather due to limited formal cooperation with some of the sources.

The main sources of information for the municipalities, regarding risks and status of natural hazards, are the FRS and the SMHI. The FRS will share information about status and development to enable better what-if analyses and planning for the municipality. The municipality will then share their analysis back to the FRS as support during an ongoing response. The information is also used to establish a COP on municipal level. The CA gathers information from a list of response actors in the county. It can be done by questionnaires to the county's municipalities, FRSs, and other relevant actors. The answers of the questionnaires will be input to the county COP, which is forwarded to MSB to establish a national COP for a specific type of event.

The COP is also used to inform the public of the risks and status of ongoing or expected natural events. Information is communicated to the public during most natural events, commonly as a weather warning via the news or applications, but sometimes there is a need to proceed to an "important message to the public" (VMA, Swe.: "viktigt meddelande till allmänheten"). The VMAs in Sweden are administered by the PSAP and communicated through public radio and television broadcasters. The messages are used to reach the public with information about an ongoing emergency with risk of affecting them, as well as directions on how to act and proceed. Sweden also has an emergency information number for public calls to get information about an ongoing emergency, fed with information from the PSAP and other agencies.

Identified needs and support suggestions: platform for regional information sharing

Interviewees from FRS and MSB wanted more accurate, timely, and useful information sharing to assist and improve the response to natural hazards. Information is the basis for COPs and originates from different sources in the ER systems. We have not been able to identify any technology to support this gathering, which seems to be done manually, by questionnaires, e-mails, and telephone calls.

Identified needs and support suggestions: tools for what-if scenario planning

The municipality and the CA perform what-if analyses and plans for potential and worst-case scenarios as a support for ongoing responses to natural hazards. The analyses are used to, e.g., inform the COPs and plan the response cooperation by identifying further actors to involve. There is no technology to support these analyses, and they are mostly done through document editors or calculus programs, e.g., MS Word or Excel.

Identified needs and support suggestions: dissemination of information through social media

Although there are several channels for public warnings in Sweden, it can still be a challenge to reach the younger generations. In a survey by the Swedish PSAP SOS Alarm (2018), 36 % of people between the ages 18-29 preferred social media as a channel for VMAs, probably because it is their main source of interaction and information. This calls for a deeper analysis into the potential of adding social media as a channel for VMAs.

Risk management

To assess the risk of natural events, most interviewees mention the importance of a consequence-based assessment. All municipalities and FRSs should do their own assessment and determine whether the identified consequences will be difficult for them to handle. For example, 10 cm of snow in southern Sweden might have high societal impact, while it will be everyday business in the north. To do quality risk assessments, several interviewees mention the need of support from actors with more knowledge of the event type, the surroundings, or operations affected by the event. Such actors could be expert agencies, companies operating in the incident area, or affected landowners.

Forecasts and warnings regarding natural events in Sweden are mostly done by SMHI, which monitors and analyzes most meteorological, hydrological, and biophysical events. Some exceptions are avalanches and landslides, which are monitored by the Swedish Environmental Protection Agency and the Swedish Geological Institute, respectively. During high risk of natural events, it is possible that the affected FRS has daily contact with SMHI for status and forecast updates.

To determine the risk of wildfires most FRSs use the Fire Weather Index (FWI) provided by SMHI. The FWI is provided in a raster of 5X5 km, indicating the fire risk in each cell, and is updated two times a day. At certain levels of FWI, the municipality and the CA can impose public fire bans to limit the risk of ignition. As an expansion to FWI, some FRSs also use Fire Behavior Index (FBI) to get informed about the fire behavior based on the weather, topology, soil type, and vegetation. During high risks of wildfires, regular surveillance by aircraft is done depending on the risk index. The surveillance is done by a contractor procured by MSB and administered by the CA. During ongoing wildfires, surveillance takes place on several levels in the emergency response system. On a local level, the FRS surveils the fire developments to determine the spread and how to distribute resources among the wildfires, with possible support from the municipality for external monitoring and worst-case analyses. On regional and national level, the PSAP does external monitoring to identify trends and deviations regarding wildfires, while MSB gathers information about ongoing fires to keep track on the national wildfire situation.

Certain natural events can be monitored using sensors and other means of surveillance. High river flow is one example, and FRS uses the measurement data to assess the risk of flooding. The data is collected from level recorders in the water course, as well as flow level forecasts provided by the SMHI. Many FRSs use flood maps, which visualizes the spread of water and risk of flooding at certain flow levels, for preventive barrier planning and identification of communities at risk. Some FRSs and municipalities also have access to flood models or maps for cloudbursts, visualizing the flow of water and vulnerable areas in need of protection. Some of these models can also identify areas under risk of subsequent debris flows and landslides.

Identified needs and support suggestions: information flow between surveillance technology and C2 center

Most FRS interviewees mentioned drones used for monitoring incident sites. However, the use is limited due to a lack of inhouse technology to transmit information between the drones and the C2 center. A more sophisticated information flow between the drones and the C2 center will support the understanding of the incident site, improve the situational awareness, and assist the establishment of COPs.

Identified needs and support suggestions: identification of public property under risk

The identification of critical public property at risk from a natural event was considered difficult by several FRS interviewees. It will set the response and preparation priority for the FRS, which mostly concerns which public properties to protect and is commonly set by policy decisions taken by the municipality. For slow and limited events, e.g., river floods, there are often preexisting checklists to support the identification, since the rivers are monitored and mapped. However, for rapid and expanding events, e.g., wildfires, the lack of supporting checklists and technologies make the analysis more difficult. It gets even more complex in multiple settings of natural events, where simultaneous or cascading aspects need to be considered, e.g., wildfires combined with strong winds.

Identified needs and support suggestions: integration of models into one platform

FRSs use models to analyze and visualize risks of river floods, cloudbursts, and landslides. While river flood models are used frequently, the active use of cloudburst models for improved prioritization is limited due to lack of model knowledge in the organizations. According to the interviewee from MSB, the narrow scope of technological solutions prevent usage by the FRS, as it is difficult to learn too many systems.

CONCLUDING REMARKS

This paper set out to address a perceived research gap where current technical solutions for handling of multiple natural hazards are not connected to the reality and needs of practitioners. To apply the practitioner/end-user perspective is something we deem crucial in a society where the hazards will likely increase, not the least due to climate changes. The empirical sample of 12 interviewees covers long-term experience of response to natural events at several leader positions in response organizations and federations. The sample is also spread over several parts of Sweden with different characteristics and challenges connected to natural events, making it sufficient to study the needs for improved response. A larger sample would arguably give more detailed insights into ER to natural hazards, but for a holistic perspective, the current was considered sufficient. Although the study case is the Swedish ER system, countries with the same ER governance structure, or with the same inexperience of multiple natural hazards, can gain insights from this study. However, studies into the needs of other countries for improved response to natural hazards are recommended, as it provide deeper insights and enables comparison between cases.

The paper illuminates a lack of technology to support decisions and analyses during emergency response to both single and multiple natural hazards. Even fundamental activities, e.g., information sharing and the establishment of common operational pictures (COPs), are mostly done manually through e-email, text-editors, or even verbally, which is surprising. The use of technology is not only a valuable support for decisions and analyses of emergency response, but it can also provide situational understanding and insights between response actors, with the potential to enhance and develop cooperation, coordination, and integration in the response system. The findings of this paper can inform policy makers and managers in emergency response systems of what challenges and needs to expect due to the threat of increased frequency and severity of natural hazards. The paper contributes to address the gap on how to manage multiple natural hazards, by describing the current management, identifying needs of information and decision support systems, and suggesting possible solutions. The findings can inform the scientific community of future research directions, and in this way encourage development of solutions to the identified needs.

ACKNOWLEDGMENTS

This research is part of the project EMMUNE, funded by the Swedish Civil Contingencies Agency (MSB) and FORMAS, a Swedish research council for sustainable development.

REFERENCES

Bird, D. K., Jóhannesdóttir, G., Reynisson, V., Karlsdóttir, S., Gudmundsson, M. T., Gísladóttir, G. (2018) Crisis Coordination and Communication During the 2010 Eyjafjallajökull Eruption, *Advances in Volcanology*, June 2017, 271–288.

Bosomworth, K., Owen, C., Curnin, S. (2017) Addressing challenges for future strategic-level emergency management: reframing, networking, and capacity-building, *Disasters*, 41, 2, 306–323.

Damalas, A., Mettas, C., Evagorou, E., Giannecchini, S., Iasio, C., Papadopoulos, M., Konstantinou, A., Hadjimitsis, D. (2018) Development and Implementation of a DECATASTROPHIZE platform and tool for the management of disasters or multiple hazards, *International Journal of Disaster Risk Reduction*, 31, 589–601.

Genovese, E., Przyluski, V. (2013) Storm surge disaster risk management: The Xynthia case study in France, *Journal of Risk Research*, 16, 7, 825–841.

Gill, J. C., Malamud, B. D. (2014) Reviewing and visualizing the interactions of natural hazards, *Reviews of Geophysics*, 52, 4, 680–722.

Greiving, S., Fleischhauer, M., Wanczura, S. (2006) Management of natural hazards in Europe: The role of spatial planning in selected EU member states, *Journal of Environmental Planning and Management*, 49, 5, 739–757.

Grottenberg, L., Njå, O. (2017) Applying a systems safety approach to the development of GIS in the Norwegian emergency management domain, In M. Cepin & R. Bris (Eds.), *Safety & Reliability, Theory and Applications* (1st ed., pp. 3297–3305), CRC Press.

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution, In *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

King, N., Horrocks, C., Brooks, J. (2019) Interviews in Qualitative Research (2nd ed.), SAGE Publications Ltd., London.

Lu, X., Xue, L. (2016) Managing the unexpected: Sense-making in the Chinese emergency management system, *Public Administration*, 94, 2, 414–429.

Miao, X., Banister, D., Tang, Y. (2013) Embedding resilience in emergency resource management to cope with natural hazards, *Natural Hazards*, 69, 3, 1389–1404.

Motamedi, M. H. K., Saghafinia, M., Bafarani, A. H., Panahi, F. (2009) A reassessment and review of the bam earthquake five years onward: What was done wrong?, *Prehospital and Disaster Medicine*, 24, 5, 453–460.

Pesigan, A., Geroy, L. S. (2009) Emergency management in the western pacific region: Current status and challenges, *Southeast Asian Journal of Tropical Medicine and Public Health*, 40, SUPPL. 1, 1–10.

Saldaña, J. (2013) The Coding Manual For Qualitative Researhers (2nd ed.), SAGE Publications Ltd., London.

Sim, T., Yu, J. L. (2018) Natural Hazards Governance in China, In *Oxford Research Encyclopedia of Natural Hazard Science* , Oxford University Press.

Simonovic, S. P., Kundzewicz, Z. W., Wright, N. (2021) Floods and the COVID-19 pandemic—A new double hazard problem, *Wiley Interdisciplinary Reviews: Water*, 8, 2, 1–18.

SOS Alarm (2018) Undersökning om kanalval för VMA - viktigt meddelande till allmänheten,.

Steelman, T. A., McCaffrey, S. (2013) Best practices in risk and crisis communication: Implications for natural hazards management, *Natural Hazards*, 65, 1, 683–705.

Su, Z., Zhang, G., Liu, Y., Yue, F., Jiang, J. (2016) Multiple emergency resource allocation for concurrent incidents in natural disasters, *International Journal of Disaster Risk Reduction*, 17, 199–212.

Theodora, Y. (2020) Natural hazards: key concerns for setting up an effective disaster management plan in Greece, *Euro-Mediterranean Journal for Environmental Integration*, 5, 2, 1–10.

Tingsanchali, T. (2012) Urban flood disaster management, *Procedia Engineering*, 32, 25–37.