SMS-based Real-time Data Collection for Evaluation of Situational Awareness and Common Operational Picture: Lessons Learned from A Field Exercise

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ABSTRACT

Managing complex multi-agency emergency operations requires that the key actors have a holistic, correct and dynamic situational awareness (SA) and that the involved actors establish a common operational picture (COP). Establishing SA and COP are key objectives in many multi-agency exercises, however, reported research shows limitations in existing methods and approaches for collecting the data required for evaluating this. By being able to capture near real-time information during different phases of the exercise we will be better positioned to identify what works well and what does not work in the process of establishing SA and COP. Our paper presents an example of real-time data collection using SMS during a multi-agency field exercise. Overall, the results support the idea of this as an effective method for collecting real-time data for analyzing the formation of SA and a COP among actors in emergency management.

Keywords
Real-time Data Collection, Emergency Exercises, Situational Awareness, Common Operational Picture.

INTRODUCTION

Because of the risk for jeopardizing the safety and quality of an emergency operation, it is difficult for researchers to observe the situational awareness of involved actors during a crisis. Thus, exercises provide the best option for studying related behavior (Wolbers, Boersma and Groenewegen, 2018). The involved agencies must enhance their capabilities to handle mass casualty incidents by practicing and evaluating new and established knowledge in full-scale regional exercises (Klima et al., 2012). Literature related to emergency management organizations request more studies focusing on the outcome of collaboration in exercises (Berlin and Carlström, 2015).

Providing training in testing collaboration, communication, standard procedures, building common operational picture (COP) and common situational understanding to enhance collaborative skills and situational awareness are training targets in many multi-agency exercises. However, reported research shows limitations in existing methods for collecting data related to emergency incidents (Altevogt, Wizemann and Reeve, 2015) and exercises

(Ingrassia et al., 2012). In addition, it is a challenge to evaluate full scale-drills involving several emergency management services because the actors have different views and perceptions based on their domain-specific expertise (Imoussaten, Montmain and Mauris, 2014) and their narrative is likely to be influenced by post-hoc rationalization (Bygstad and Munkvold, 2011). This represents a problem, since evaluations are mostly based on observation, textual sources such as reports and post-hoc interviews, and less on real-time data reflecting the actors' SA during the exercise. The practices in emergency management are highly contextualized and the involved actors "*often cannot articulate how they do what they do unless they are in the process of doing it*" (Barley and Kunda, 2001, p. 85).

When handling emergencies, first responders and their collaborating organizations make decisions and perform actions based on the recognition of an event, the interpretation of their observations and predictions of the outcome in different settings (Berlin and Carlström, 2008), which are all core elements of SA (Hunter, Porter and Williams, 2019). Further, an actor`s level of SA provides a crucial foundation for decision making (Endsley, 1995). The individuals` explanation of the situation is exchanged with collaborative actors and then negotiated into a shared social information (Stieglitz, Mirbabaie and Milde, 2018) derived from the common goals. The actors` SA at different stages in the operation has a huge impact on the process for building a COP (Steen-Tveit, Radianti and Munkvold, 2020), which is shown to be an important component in making an emergency operation efficient (Karagiannis and Synolakis, 2016).

This paper presents a field experiment of using a SMS-based survey method for near real-time data collection among important decision-makers during a full-scale regional exercise with a forest fire scenario. The SMS consisted of a link to a small survey with eight questions and was delivered to fifteen key actors in two different stages of the exercise. The questions concerned the actors` SA and whether they had access to sufficient information for establishing SA. Based on analysis of the SMS responses and interviews with participating actors about the method after the exercise, the paper presents lessons learned and recommendations for future real-time data collection using SMS. As will be illustrated, this method provides a possibility to measure the differences in the actors' SA on important elements of the emergency situation at given stages in the operation, and further compare this information to evaluate to what degree a COP is established.

The next section briefly presents a summary of SA and COP as a foundation for successful emergency management, and some currently used evaluation practices. Then the method for collecting the real-time data is described, followed by results from the survey during the field exercise. Finally, the findings are discussed and implications for further use of the SMS data collection method for evaluating SA and COP in multi-agency emergency operations are presented.

RELATED RESEARCH

Organizations that handle emergencies must make important decisions with potential crucial outcomes based on minimal information and under high time pressure (Magnussen et al., 2018). Live full-scale exercises provide an important environment for learning about the collaboration processes in situ and contribute with a possibility for eliciting the actors` cognitive and emotional response similar to the responses in real events (Waring, 2019). The involved actors` intention is to achieve a collective perception, however in evaluations they are most likely to transfer their own perception of the situations based on their own professional standpoint (Imoussaten et al., 2014). The evaluation of multi-agency exercises seems to be mainly relying on textual sources such as reports, observations and interviews. Therefore, objective evaluation is an issue (Gryth et al., 2010) because of the different situational understanding and knowledge among the various decision-makers (Ju and Wang, 2012). Post-hoc interviews rely on the actors` memories of the situation and one must consider that people forget and that memories are an ongoing process. For instance, it is difficult to separate memories and beliefs because they rely on each other (Shaw, 2018) whereas *"Memories are beliefs about what happened, and beliefs are constructed from, and reinforced by, memories"* (Raye, 2000, p. 36). Real-time data collection can provide valuable insights in situ and avoid some of the memory biases that might occur.

Over the past 40 years, SA as a factor in human decision-making processes has been a focus for a considerable amount of research in different domains. Endsley's (1995) SA theory is one of the most influential models in this research, based on the following definition: "*Situation Awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and projection of their status in the near future*" (Endsley, 1995, p. 36). Research from the aviation industry has shown that lack of SA as a human factor might lead to poor outcomes and errors in the management of operations (Endsley and Garland, 2000), and notably 88 % of the major accidents in aviation has been related to poor SA (e.g. Cak, Say and Misirlisoy, 2019; Endsley, 1995). Endsley's model divides SA into three levels that can be analyzed: (1) perceiving the elements in the environment, (2) comprehending the current situation, and (3) projecting the future status of the situation (e.g. Endsley, 1995; Endsley and Garland, 2000). Based on this concept it is possible to investigate how individuals

develop SA and what it comprises (Stanton, Salmon, Walker, Salas and Hancock, 2017). Another interpretation of SA is "*the combining of new information with existing knowledge in working memory and the development of a composite picture of the situation along with projections of future status and subsequent decisions as to appropriate courses of action to take*" (Fracker, 1991; cited in Salmon et al., 2007, p. 408) This definition emphasizes how the actors combine existing knowledge and experience into the individual development of SA, coupled to the dynamics in the situation they are in at different stages in time. Time itself is thus an important factor to consider regarding each actor`s SA because SA is connected to how the situation evolves (Fracker, 1991).

One can measure the performance of an exercise, but the measurement of SA can provide a greater sensitivity of the evaluation when considering SA as a state of knowledge in a dynamic situation (Endsley and Garland, 2000). However, the process of achieving SA also involves several cognitive processes that are more complex to measure than to evaluate the state of knowledge at different stages in an event (e.g. Edgar et al., 2018; Luokkala and Virrantaus, 2014; Salmon et al., 2008). There are several methods for evaluating different Command and Control Center (CCC) operators` SA such as SAGAT, SPAM, response time, errors (Endsley, 2019). SAGAT is a method where they perform different simulations of tasks or scenarios. At selected times, the performances are frozen and the actors` answers questions either verbally, in writing or on a computer. This is a real time data collection method that is found to be highly sensitive, and criticism of this says that the freezing of the scenarios is intrusive. SPAM is a real time data collection method that avoids the freezing, where the actor is asked verbally while he or she perform the operational tasks. Nevertheless, criticism have also been raised about the intrusiveness of SPAM (Endsley, 2019).

The different actors` SA is a crucial factor for the success of the operation, however, the COP is another important component related to multi-agency operations. Norway experienced a terror attack in 2011 where the commission report concluded that we need to improve the focus on SA and COP. As a direct consequence, a new collaboration principle was added to the Norwegian emergency preparedness regulations (Norwegian Government, 2017). Therefore, an important focus in the crisis management domain is the SA and how the actors build a COP. The actors` SA is an important foundation for building a COP, and SA can be considered as an emergent property of the interaction between an individual and the surroundings (Edgar et al., 2018).

Since the emergency management services have become more specialized (Axelsson and Axelsson, 2006), the different organizations must collaborate for achieving the best possible outcome in large crisis operations (e.g. Kapucu, 2008). To be efficient in the collaboration process it is important to share critical information for building and maintaining a COP. This is accomplished by a process of connecting the agency-specific actions into a common arrangement (Wolbers et al., 2018) and further collect operational specific static and dynamic information from different sources in the environment and share the common information needed with the relevant organizations (Blandford and Wong, 2004). However, even though collaboration exercises are supposed to improve cross-sectional interactions (Kim, 2013), collaboration is proved to be hard to practice even in collaboration exercises, and the outcome has limited usefulness in real operations (Berlin and Carlström, 2008; Berlin and Carlström, 2015). Why this seems to be the case is an ongoing discussion, and literature shows different examples such as inadequate focus on learning aspects and too much dependence on standards (Sørensen et al., 2019). Other findings indicate that the focus is mostly on internal routines and skills, and less on collaboration capacities (Andersson, Carlstrom, Ahgren and Berlin, 2014). Another reason could be the lack of dynamic information on the different involved actors` state of knowledge in various stages of the emergency operation, as this might provide a deeper understanding of the operational features that elicit decision-making of several actors simultaneously. The ability to discover specific important features that strengthen or prevent success in crisis management operations is an essential step towards an effective evaluation (Ingrassia et al., 2012).

SCENARIO AND METHODOLOGY

Scenario

We tested our proposed method for evaluating SA during a full-scale emergency exercise held in Norway. Every year, the County Governor's offices in Norway run this type of exercises in their respective region. The one-day exercise took place in September 2019 in two inland municipalities in southern Norway. The exercise scenario was an industrial fire that spread to the nearby forest, creating needs for evacuation of inhabitants in the affected area. The scenario also included search for a missing person. The purpose of the exercise was to train the first responder agencies and the municipal crisis management team on how to handle a serious incident and thereby strengthen crisis management skills (cooperation, coordination) and planning for such a complex scenario.

Methodology

We planned the field trial of the evaluation method via SMS with the exercise organizer, to prepare for conducting

the data collection and investigate several elements of the key organizations` management of the crisis. Table 1 shows an overview of the respondents in our data collection.

Table 1: Respondents

Organization	Role	Data collection
Fire services	Site commander	SMS + Interview
Fire services CCC	Emergency dispatcher	SMS + Interview
Ambulance	Site commander	SMS + Interview
Ambulance CCC	Emergency dispatcher	SMS
Ambulance CCC	Site commander	SMS
Police services	Operative unit	SMS
Police services	Site commander	SMS + Interview
Police services CCC	Emergency dispatcher	SMS + Interview
Municipality	Emergency coordinator	SMS + Interview
Municipality	Emergency coordinator	SMS + Interview
Municipality	Municipal Chief Executive	SMS + Interview
Media college	Journalist student	SMS
Media college	Journalist teacher	SMS
Red Cross	Site commander	SMS
Red Cross	Operative Unit	SMS
County Governor`s office	Counsellor	SMS + Interview

The respondents included key actors, ranging from the first responder services (police, fire and health services), two involved municipalities, the county governor's office and the voluntary organization Red Cross. All these actors had some degree of authority to make decisions. In addition, the SMS also was sent to one teacher and one student at a local media college acting as reporters to cover the emergency situation. Three actors who received the SMS did not answer. It could be several reasons for the missing response. They may have overlooked the SMS or may have been prohibited from responding due to the high time pressure in their operation. As these actors did not respond to any of the two SMS messages, the answers to the first and second SMS are from the same respondents.

SMS survey

The questions in the SMS survey (Table 2) were based on some of the important elements in achieving SA such as receiving information (questions 1,2 and 3), how to comprehend the information (question 4), prediction of future status (question 5) and knowledge about available resources (questions 6 and 7). The seven questions were administered using SurveyXact (SurveyXact.no). Some of the questions were designed as multiple choice (shown in Table 3), and also with possibility to include a free text response to elaborate. An example would be question 2 "Who gave you the latest situation report?" where the option; "other" (see question 2 in Table 2) had an open line to elaborate the answer, thus who gave the latest situation report.

Table 2: Questions in the SMS

Number	Question
1	Have you been provided with sufficient information to form an understanding of the situation?
2	Who gave you the latest situation report?
3	How did you receive the information?
4	How do you understand the scope of the fire?
5	Which of the following critical community features do you believe is threatened?
6	Are all necessary resources for managing the situation present?
7	Do you know the location of the other resources?

Two actors from the Ambulance services and the Ambulance Command and Control Center (C3) functioned as pilots and received the SMS some time before the exercise to provide us with possible improvements and clarifications. This led to some updates to the original questions. The participants in the exercise were contacted a few days in advance and asked if they were willing to receive the SMS survey on their private cell phone. A day in advance, researchers provided a reminder to all confirmed participants, also via SMS, on this SMS survey under the exercise. The SMS was sent from the researchers` lab at two occasions selected based on the scenario

description, see timeline in Figure 1.

Figure 1: Exercise timeline

The content of the SMS provided the privacy statements for handling the data, brief information of the project, and the timeline for answering the questions, i.e. within fifteen minutes after receiving the message. The SMS contained a link to the survey.

Interviews

Nine interviews were conducted during the week after the exercise. The semi-structured interviews mainly covered questions about the participants' different working methodologies and tools, but they were also asked about their experience with receiving the SMS during the exercise. The interviews were performed by four different researchers, lasting from 45 to 60 minutes. The interviews were all recorded and transcribed in full.

FINDINGS AND DISCUSSION

Table 3 summarizes the responses of the two rounds of the SMS survey.

Table 3 Responses from the two rounds of SMS data collection

Questions	First SMS		Second SMS	
	Answer	%	Answer	%
1. Have you been provided with sufficient information to form an understanding of the situation?	Yes (8/13)	57%	Yes (6/9)	67%
	No (5/13)	43%	No (3/9)	33%
2. Who gave you the latest situation report?	Own CCC (3/13)	23%	Own CCC (3/9)	33%
	Other CCC (1/13)	8%	Other CCC	0
	Operative Unit (5/13)	38%	Operative Unit (1/9)	11%
	Other (4/13)	31%	Other (5/9)	56%
3. How did you receive the information?	Specific call group (2/13)	15%	Specific call group (2/9)	22%
	BAPS*	0%	BAPS*	0%
	Other common call group	0%	Other common call group	0%
	Phone call (5/13)	39%	Phone call (1/9)	11%
	Verbally from colleagues (6/13)	46%	Verbally from colleagues (6/9)	67%
4. How do you understand the scope of the fire?	Small-controlled (1/13)	8%	Small-controlled	0%
	Medium-controlled but can evolve to uncontrolled (4/13)	31%	Medium-controlled but can evolve to uncontrolled (3/9)	34%
	Big-uncontrolled (3/13)	23%	Big-uncontrolled (4/9)	44%
	I don't know (5/13)	38%	I don't know (2/9)	22%
5. Which of the following critical community features do you believe is threatened?**	Housing (6/13)	50%	Housing (4/9)	44%
	Electronic communication (1/13)	8%	Electronic communication (1/9)	11%
	Accessibility (5/13)	42%	Accessibility (4/9)	44%
	Energy supply (1/13)	8%	Energy supply (1/9)	11%
	Vulnerable group (4/13)	33%	Vulnerable group (6/9)	67%
	Operative personnel (5/13)	42%	Operative personnel (3/9)	33%
6. Are all necessary resources for managing the situation present?	Yes (5/13)	36%	Yes (2/9)	22%
	No, we lack some (5/13)	36%	No, we lack some (5/9)	56%
	I don't know (3/13)	28%	I don't know (2/9)	22%
7. Do you know the location of the other resources?	Yes (9/13)	56%	Yes (6/9)	67%
	No (4/13)	44%	No (3/9)	33%

* Collaborative call group for fire, health and police.

** Respondents could select more than one answer.

First SMS: The SMS survey provided answers from several key actors in the exercise (ref. Table 1). Questions 1, 2 and 3 concerned receiving information for building SA. The first question asked if the participant perceived to have sufficient information to form an understanding of the situation. The first SMS survey was distributed one hour after start of the exercise, and the situation had just been escalated by a fire in a factory with people inside (see timeline in Figure 1). The answers indicate that the majority (57 %) perceived to have sufficient information at this stage. However, it is somewhat surprising that as many as 43 % of the key actors experienced that they did not have enough information to form SA. Using the Norwegian Public Safety Network (NPSN), which is a common collaborative platform for both internal and inter-agency verbal communication, it should be possible to provide complementary information to all key actors simultaneously, and thus provide the involved stakeholders with shared information needed for building a COP. However, not all municipalities have yet taken the NPSN in use.

The observed differences in the perception of having been provided with sufficient information or not may have several reasons. Firstly, from the answers of Question 3 (Table 3) the information seems to be spread verbally from colleagues on site or in the communication hubs (46 %), and not via the NPSN. This shows that the information mainly did not come directly from the CCCs but seemed to be communicated on site. Secondly, since the Norwegian emergency management services do not have other shared information systems such as a common map interface, the reported lack of situational understanding may indicate that verbal descriptions only are not sufficient to form a SA in this kind of complex scenario. Thirdly, it may indicate that the provided or available information flow did not fulfill the different actors` internal information needs. The answers to Question 2 might indicate the natural communication paths because of the many different emergency management services involved using different tools and procedures for communication. However, since no communication was provided in the collaborative call group (BAPS) (Question 3) or by other CCC (8%) (Question 2), there seems to be limited common information provided in the NPSN. Overall, the response to Questions 1, 2 and 3 show a lack of any fixed structure in the information sharing process for building a COP. The answers to question 4 showing divided understanding of the scope of the fire, indicate that the communication flow did not satisfy the information needs. This assumption is reinforced by the answers to Question 5, showing relatively little consensus on the threats from the fire to different critical community features, and thus indicating a lack of established COP in this area. The varying responses to Questions 6 and 7 also accord with the observation from Questions 1 and 4, that the SA was limited at this stage of the crisis.

Second SMS: The second round of the SMS survey was sent three hours into the exercise, when the situation had escalated, and the fire had spread to the surrounding forest area (Figure 1). While the fire was still developing also in this stage, the answers to Question 1 related to receiving information indicate that the majority of the actors had been provided with sufficient information to a greater extent than earlier in the operation, thus reflecting a higher degree of SA. Regarding building a COP, the information was still mainly shared verbally outside the NPSN, except for 22 % shared in a specific call group. The answers still show some differences in the perception of the scope of the fire (Question 4) and the threatened community features (Question 5). Answers to question 6 and 7 show that over 50 % experienced that this crisis required more resources than what were available at this stage of the operation, and that 67 % knew where the involved resources were at that time. Based on this, we assume a COP had been established in this particular area.

The responses from the second SMS indicate that the actors had a better understanding of the situation and to a greater extent experienced to have sufficient information about the fire in order to have an adequate situational understanding. However, the answers also indicate several differences in the perceptions which may be caused by several reasons, for instance, even if the operation had lasted for three hours, there were many organizations involved at various locations, using different technological tools, and with different tasks and goals. Naturally, the organizations in their handling of the situation will focus mainly on their own information needs. Time may not allow for obtaining knowledge on the tasks of other actors, and the key information must be in focus. With 56 % responding that the available resources were insufficient, one can assume that the operation was partly hectic.

Interviews results

Out of the nine actors we interviewed, six had answered one or both SMS surveys. From the interview we learned that one of the actors who was not responding got interrupted when she tried to answer the survey. The other two were functioning as operative personnel. One of them explained the lack of participation by forgetting it, he did not heed his cellphone throughout the exercise. The other participant experienced too much time pressure and the tasks she was responsible for could not be interrupted. The key goal for the operative units in the exercise was training on collaboration and coordination at the emergency site and checking their cellphone could be difficult in this situation. However, several other operative units did answer, this can be explained by the varying number

of tasks both in general and at the specific time when they received the SMS. Several actors mentioned the time pressure in the interviews and emphasized that such exercises tend to be very hectic. Some also pointed out that they were a bit stressed out when answering the survey. This is also the reason why three actors only had time to answer the first round. Two actors suggested that the exercise management ought to remind the participants to answer the survey, one of them stating that *"in collaboration with the exercise management, I would like someone to tell me: "now (name) take five minutes timeout", and then I would be more prepared to answer".* Another participant from a CCC suggested to be reminded via their own information system such as internal mail, as then the reminder would be visible in their working area. The cell phone is typically not in focus in these situations.

The participants on the whole demonstrated clear opinions about the method and were mainly positive and expressed understanding for the purpose. They also appreciated the goal for the SMS, because evaluation of SA and COP is difficult and important areas for practice. An interviewee pointed out that it was absolutely necessary that they were prepared for it and knew why they should answer, and what the results could provide. Without this, it could be perceived as a disruptive element. This view was echoed by another informant who argued that it was crucial that the idea of sending the SMS was introduced early in the planning process, and by this preparing the actors. It can be difficult to implement new elements in such hectic environments and established processes as this type of exercise, and it might be even more difficult when it is researchers and non-practitioners who introduce it.

When asked about the content of the survey, some informants argued that it should be possible to answer with more nuance, for example as one interviewee said; *"It was a bit simple, I had many things I would like to explain"* and another commented that; *"I would like to have more possibility to differentiate the answers, the outcome might be too simple like this (...)"*. Yet, none of the participants provided any textual elaboration to the questions opening for this (see Table 3). This suggests that the survey should consist exclusively of multiple-choice questions and not rely on open answers. Overall, the comment "*I think it was good that it was relatively short, or else it would be too complex to answer"* illustrates that this kind of data collection in such environment must be simple and quick to answer. Still, it could be considered to provide more response alternatives for some questions, for greater detail and nuance. One option could be to arrange the possibility for the respondents to verbally answer by a voice message.

CONCLUSION

The aim of this research was to examine how we can use SMS to be able to capture near real-time information during different phases of an exercise, and to analyze whether this can make us be better positioned to identify what works well and what does not work in the process of establishing SA and COP. The results from the two rounds of the SMS survey provided some indicators of the participants` SA in the two stages. Further, it is possible to discuss the COP when investigating the differences and similarities in the answers.

The results of the qualitative interviews support the idea of this being an effective and fruitful method for collecting real-time data, however, it is important to consider the high time pressure and complex tasks in emergency exercises. While this method seems promising for analyzing SA, it should be implemented cautiously to maintain balance between the use of too simple and too complex questions and response options. In addition, open questions should be avoided. Further, it is important to incorporate this type of data collection early in the exercise planning, to be able to prepare the participants and ensure their contribution.

However, this method also has some limitations that should be considered in future studies. Emergency operations, even exercises, create a stressful environment which can hinder the informants from answering, or influence the accuracy of the answers. In addition, exercises are always different from real events in various ways (Berlin and Carlström, 2014) and the logic in the working processes might be different from real events and further influence the answers. While the differences in collecting data from a link instead of personally asking the informants (such as in SPAM and SAGAT) provide some issues such as the possibility to ask follow- up questions and clarify answers, there are also some benefits. For instance, the disturbance is less than having a researcher coming into the emergency site during the operation, which again may impair the realism and tamper with the actors' structures (Ingrassia et al., 2012). Further, there is no influence from the researcher, and it provides the opportunity to simultaneously include a large number of respondents.

Despite these limitations, the study offers relevant implications for near real-time data collection. A natural progression of this work is to develop the questions to be as easy as possible for the participants to answer in such hectic situations. Further experimentation using a broader range of the possibilities of smartphone technology, such as GPS for investigating the connection between level of SA and the location of the actor, is recommended. Lessons learned from our experiment shows that open questions will not be answered, but that it perhaps should be more response alternatives provided. Former studies report challenges for novice first responders in handling the workload due to limitations in their attention and working memory capacities (Cak et al., 2019), and the real-

time data collection suggested by our method might reveal differences in the SA between novices and experts. Through this one can identify what elements that must be strengthened in the training processes of novices. This potential should be addressed in further research.

This study represents a first attempt to examine the use of SMS-based data collection for analyzing the formation of SA and a COP among actors in emergency management. We plan to further test this method in different exercise scenarios, to refine the method and its use.

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