# Supporting Collaboration in Human-Machine Crisis Management Networks

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**Abstract.** Several parts of our modern lives are today taking place in networks where both humans and machines are key actors. With this development follows the increased need and importance of investigating related consequences and understand how we best can design technological systems to support efficient and productive human-machine networks. This paper presents the use of a human-machine network approach to nuance how we think of the interactions and collaboration that takes place in human-machine networks. Specifically, we study the complex network involved in crisis management, and show how such a network's characteristics may have implications for, and affect collaboration. The study is based on the analysis of in-depth interviews with both system provider representatives and end-users of a collaborative tool for crisis management. Three directions in which the design and development of crisis management systems should be guided are proposed.

**Keywords:** Human-machine networks · Crisis management networks
Collaborative tool

## 1 Introduction

We live in a highly-connected world where technology has undeniably become an integrated part of our personal and professional lives, supporting us in conducting a range of tasks. Often when we interact with technology, we are a part of a larger human-machine network (HMN), assemblages of humans and machines that interact to produce synergistic effects [1]. This acknowledgement of both humans and machines being vital parts and having active roles in the network, which is often overlooked and a gap in current research, is crucial if we in the future are to tackle the design challenges HMNs constitute [2]. Knowledge and awareness of human and machine actors involved in the network, the interactions between them, and their embedded capabilities and behaviors is a requirement for creating successful networks [1].

The value of HMNs is perhaps especially visible when people have to solve complex tasks that require high degrees of coordination and information sharing. Crisis management represents such a domain, consisting of HMNs where technological systems and a variety of human actors, interact and work together towards achieving the common goal of saving human lives and other values important to society [3]. Technological systems for crisis management have the purpose of facilitating efficient collaboration


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between humans – a core requirement for successful management – through supporting coordination by providing information, an overview of the situation, and decision support. However, inadequate or the lack of well-designed and well-functioning crisis management systems is often a contributing factor to collaboration failing [4, 5]. There is a strong need for such systems to better support the collaborative work that crisis management entails. As modern crisis management is taking place in networks where both humans and machines are key actors, it becomes increasingly important to investigate related consequences and understand how we best can design technological systems to support efficient management of crisis events.

Through our research, we aim to show how a HMN approach and analysis may influence how we consider and think of HMN and their characteristics. Specifically, we study how the characteristics of a crisis management network may have implications for, and affect collaboration. By this, we aim to provide designers and developers of crisis management systems with an understanding of crisis management as a complex HMN where different dimensions of the network should be considered.

We build our research on the HMN typology proposed by Eide et al. [6], which presents an opportunity to understand and discuss design challenges and issues within HMNs according to the network actors, the relationship among them, its extent, and how the network is organized. Based on this typology, we investigate a crisis management network that draws on information from multiple sources to facilitate dynamic collaboration across the actors of a potential crisis. The study involves in-depth interviews with 6 system provider representatives and 6 end-users of a collaborative tool for crisis management.

## 2 Challenges of Crisis Management

Crisis management involves several comprehensive phases and activities, including preparedness, prevention, protection, mitigation, response, and recovery [7, 8]. To be able to manage these activities, coordinated collaboration, cooperation, and transparency between people from a variety of agencies and organizations is required [3] - all of whom possess complementary knowledge and skills needed for efficient crisis management. Such collaborative teamwork is often chosen within complex domains where desired outcomes cannot be accomplished by individual efforts alone [5].

Crisis incidents occur in several forms and vary in origin [9], from natural disasters (e.g. floods, snowstorms, droughts), to accidents caused by human or technological errors (e.g. offshore oil spills, traffic accidents, industrial accidents), or man-made as intended acts (e.g. school shootings, terror attacks). As such, the people managing crisis incidents are often working under conditions characterized by uncertainty, stress, time pressure, and lack or overload of information [10].

During recent decades, a variety of technological solution have been developed to support crisis management, especially focusing on the establishment of situation awareness and decision-making [11, 12]. Crisis management systems have been recognized to have the ability to enhance crisis management by, e.g., improving situation assessment and awareness, support decision-making, coordination of actions, and the exchange of

information [13]. Designing systems meant to support a variety of people and organizations is obviously a challenge, as each actor might have their own needs that a system should be able to account for. At the same time, the system being generic is exceedingly important for collaboration and shared coordination to be possible.

Improving collaboration in crisis management can have highly positive effects and can contribute to saving human lives. We must therefore strive to gain in-depth knowledge of elements affecting collaboration, and how to best facilitate good collaboration structures where both humans and technology is considered. As crisis management is carried out in collaborative networks where both humans and technological systems are key to efficient management, it becomes increasingly important to study what the current implications on collaboration are, and understand how we best can design such technological systems for the domain.

## 3 Human-Machine Networks

Human-machine networks are assemblages of humans and machines that interact to produce synergistic effects [1]. As such, crisis management constitute a human-machine network where people and systems interact to solve complex tasks in the environment of crises. By looking at crisis management from a human-machine network perspective, we are able to explore different elements of the network that affect collaboration.

### 3.1 The HUMANE Typology

The human-machine network typology proposed by Eide et al. [6], named HUMANE, presents an opportunity to understand and discuss design challenges and issues within a network. HUMANE is helpful in understanding which implications the characteristics of the crisis management network has on collaboration, and can provide valuable insight on how to strengthen the design of future crisis management systems to better support collaboration and efficient crisis management.

The proposed typology includes four analytical layers (Actors, Relations, Extent, and Structure), each with two dimensions that should be considered by system designers and developers. Table 1 provides an overview of the analytical layers and dimensions in relation to each other.

**Table 1.** Overview of analytical layers and dimensions of the HUMANE typology.

| Analytical layers | Dimensions |
|---|---|
| Actors | 1. Human actors |
| | 2. Machine actors |
| Relations | 3. Social ties strength |
| | 4. Human-machine relationship strength |
| Extent | 5. Size |
| | 6. Geographical reach |
| Structure | 7. Workflow interdependence |
| | 8. Organization |

The analytical layer Actors includes the two first dimensions (1) *human agency* and (2) *machine agency*. This layer and its dimensions consider the capacity and possibilities of the network actors, both humans and machines, in terms of what they are able to do and accomplish. Within this lies the activities the actors can perform, actors' opportunities to freely interact and influence other actors, and behaving unpredictably [2].

The layer Relations consists of the two next dimensions, (3) *social tie strength* and (4) *human-to-machine relationship strength*. This layer addresses the relations that exists both between humans in the network, and between the humans and the machines. One is here interested in looking at the level of which human actors are connected by remote or close affiliation, the duration of the relationship, and if the relationship is of a mutually supportive character. Regarding the relation between humans and machines, the topics of interest are the level of trust and acceptance people experience towards a machine, as well as dependency.

The Extent layer includes the next two dimensions, namely (5) *size* of the network and (6) *geographical reach*. The layer and dimensions concern the number of human nodes in the network, the network's growth rate, transnationality and cultural diversity.

Finally, the analytical layer Structure consists of the final two dimensions, (7) *workflow interdependence* and (8) *organization* of the network. The layer tells the story of how the network is structured, touching the level of interdependencies, coordination, and collaboration between human actors, and to which degree the network is fixed or flexible to change, organized in a centralized or predetermined manner, and regulated by policies.

The scale of each dimension range from low, to intermediate, to high. By using the HUMANE typology to profile crisis management networks, we are able to identify implications of the network characteristics and related design challenges that are helpful in guiding the design and development of future systems for crisis management.

## 4 Methodology

To explore the elements affecting collaboration in crisis management networks from a human-machine network perspective, we conducted a study that followed the HUMANE approach [6]. This involved defining the network characteristics and creating a network profile, identifying implications connected to collaboration, and providing informed design suggestions.

The study was carried out between September and October 2016 within a Western European country. The scope was public crisis management, and the system or machine in focus was a collaborative tool commonly used by the public crisis management organizations in the respective country, as well as by several private organizations, to maintain shared situational awareness and support decision-making. The tool, which in this paper will be referred to as the Crisis Management Tool (CMT), is a module-based tool with flexible functionalities so that it can be adapted to different organizations' needs. As such, the tool is flexible and fit for supporting the management of a variety of crisis incidents. Due to the CMTs exposure to competition and anonymity promised to

the participants of this study, more specific details about the tool and the study context will not be provided.

In the following, details of the study will be described. Figure 1 gives a brief overview of the sample, method, and themes of the study.

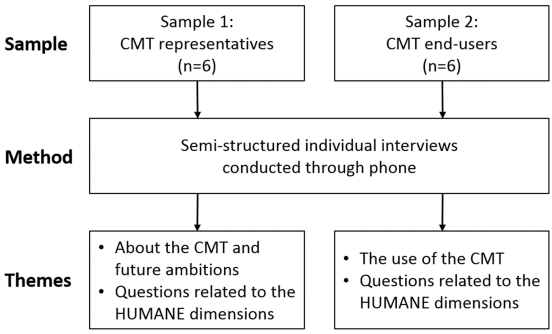


**Fig. 1.** Study overview

### 4.1 Participants

Two groups of participants were involved in the study. The first group consisted of six *representatives* of the CMT, which where people working within the company providing the tool. This group of participants were recruited through a contact person within the company, which chose the representative that were seen as appropriate for the study.

The second group consisted of six *end-users* of the CMT, which where people within different public sector organizations working with the management of crises, and that used the CMT in their work. The end-users were recruited by the one of the authors contacting them directly through phone. These end-users were selected based on their extensive experience and involvement with using the CMT.

### 4.2 Interviews

Semi-structured interviews were chosen as the method for data collection. This method gives the participants opportunity to talk relatively freely about their experiences and perceptions [14], guided by questions related to the interview topic. Two interview guides were developed, one for each group of participants. Participants were interviewed individually through phone by one of the two authors.

In the interviews with CMT representatives, the aim was to get an overview of the CMT and extract information on possible challenges related to the design of the tool. The representatives were first asked to describe the CMT in general, together with the company's future ambitions for the tool. Further, they were asked to describe the current and desired future state of the CMT network, in accordance with the dimensions of HUMANE. The interviews lasted approximately 45-60 min.

In the interviews with the CMT end-users, questions were formulated to specifically extract end-users' thoughts on challenges and implications regarding the current use of

the tool and the state of the human-machine network. End-users were first asked to describe how they used the CMT. Following, participants were asked to answer questions related to the HUMANE dimensions, in addition to describing related challenges and implications, and possible solutions. The interviews with the end-user lasted approximately 30-45 min.

### 4.3 Data Analysis

Interviews were audio recorded and transcribed, which were used as the basis for the analyses. The analyses included visual profiling of the human-machine network in accordance with Eide et al. [6], as well as identification of implications and design suggestions.

To support the profiling activity, the HUMANE Network Profiler was used [15]. The profile of the CMT human-machine network was reached by the two authors first profiling the network individually based on the interviews with CMT representatives and end-users, and then conducting a joint profiling. During the joint profiling session, inconsistencies and disagreements in the profiles were discussed and resolved.

Implications and design suggestions were identified through a thematic analysis [16] of the interview data, conducted by one of the authors. Specifically, themes containing elements affecting collaboration was extracted. The analysis and results were validated in a workshop with the CMT representatives.

## 5 Findings

The analysis resulted in the development of a profile of the network, as well as the identification of implications and related design suggestions. The elaboration on implications and design suggestions will be concentrated around the dimensions that have clear and reasonable improvement potentials.

### 5.1 The Network Profile

A visual representation of the CMT network is presented in Fig. 2. The profile is a result of the interviews with both CMT representatives and end-users combined. The numbered circular points connected by the solid line marks the network score as it is today, for each dimension. The smaller circles connected by the dotted line marks the desired future score that can potentially strengthen collaboration in the network.

The closer a point is to the boundary of the octagon diagram in Fig. 2, the higher the score, whereas points closer to the center of the diagram, indicates a lower score. Table 2 lists the current and desired future score of each dimension.

In the reminding of this section, we discuss how to better support and strengthen collaboration within crisis management through the design of such networks. Based on the profile analysis, the following presentation of results and discussion will mainly be concentrated around the dimensions where we have identified deviations in current vs. desired future state. The current scores of the studied CMT network will be described

and seen in connection to its implications on collaboration. Suggestions as to how to mediate the current implications and move towards the desired future scores are then proposed.

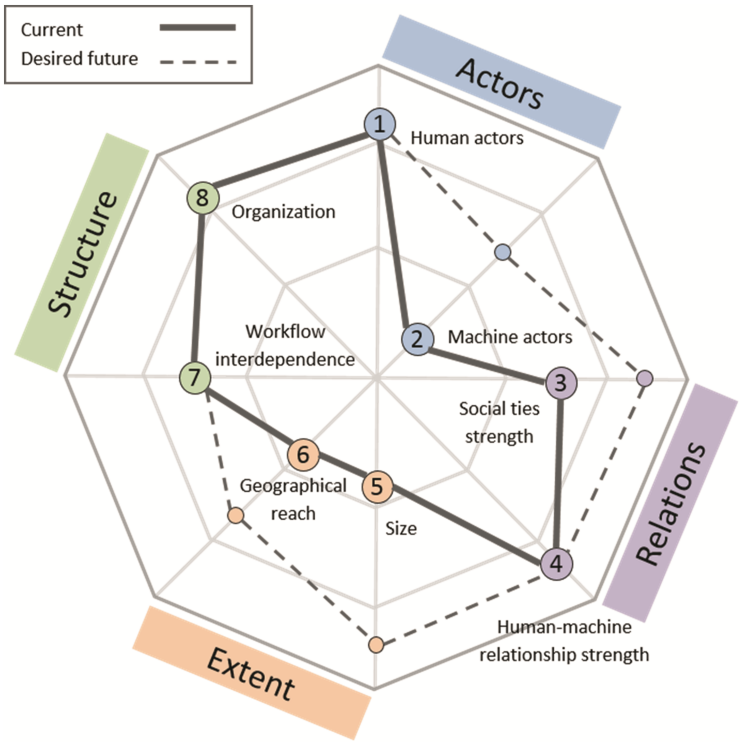


**Fig. 2.** Visual profile of the CMT network

**Table 2.** List of dimensions and their current and desired future score for the CMT network

| Dimensions | Current | Desired future |
|---|---|---|
| 1. Human actors | High | – |
| 2. Machine actors | Low | Intermediate |
| 3. Social ties strength | Intermediate | High |
| 4. Human-machine relationship strength | High | – |
| 5. Size | Low | High |
| 6. Geographical reach | Low | Intermediate |
| 7. Workflow interdependence | Intermediate | – |
| 8. Organization | High | – |

### 5.2 Increasing Machine Agency Through Higher Degree of Automation

In the studied CMT network, human agency is today high while machine agency is low. This implies that the humans in the network have a great degree of freedom to adapt the CMT to fit their organizational activities and tasks. Although there is a high level of human agency in the network, the degree of freedom humans are given varies. Within crisis management organizations, users of the CMT may have different roles, which means they are given different authorizations or levels of access in the tool. Some information might for example be protected or limited-access information, only accessible to some individuals. This may have implications on collaboration, e.g. if a person is not given the access to information that he or she needs in order to carry out tasks and actions. At the same time, it is important to make sure information is not distributed to people unnecessarily, as it can lead to information overload.

The CMT performs few tasks on its own. Rather, the tasks performed by the tool are largely predetermined by how human actors in the network has configured the system. In other words, for the CMT to function in an optimal manner where the tool supports the humans in performing their activities, the CMT first needs to be customized and fed with the needed input. A CMT representative explains this as follows.

> *"There is not much automation in the CMT. In the vast majority of cases, an event is initiated by a user detecting that something has occurred. From here, the CMT can handle some things automated based on data put in to the tool. Special warnings can be sent out to predefined lists of people, etc., and the CMT can retrieve the correct action and contingency plans according to the input the tool has received."* (CMT representative)

Appropriate utilization of the CMT thus requires that its users have the resources to and knowledge of how to configure the tool, which is currently lacking for many users within public crisis management organizations. This has implications for how users experience the tool and its usefulness. The following two quotes exemplify this challenge.

> *"We would like to automate the incident potential based on the action plans. And I know that it is possible, but it's just that it needs to be done. The fact that our organization ourselves must do this requires quite a bit. I wish that they could standardized this process a bit more. Unfortunately, we have few resources."* (CMT end-user)

> *"There are very many clicks, and you have to click here and you have to click there, and you have to somehow create categories. In addition, I don't think it has been easy to find material that describes how this should be done."* (CMT end-user)

As the quotes illustrate, some end-users experience the CMT as challenging to use due to the configurations that must be made to the tool. In addition, finding out how to configure the tool is not always intuitive and information on how to do it is not, to a large enough extent, made visible and available. Providing guidance in how to best configure the CMT might help users utilize the tool more effectively.

Systems for crisis management are often intended for use by several crisis response organizations. Therefore, they are usually designed with high levels of human agency and low levels of machine agency, where a systems usefulness relies on the human actors' ability to configure the system to fit their organization's needs. The background for this design rational may be the varying requirements and needs of different user

organizations. Thus, such systems are designed to be flexible enough to fit the needs of several different user organizations. When considering automation into the design of crisis management systems, it is important to keep in mind the unpredictable environment in which crisis management takes place, something that is, according to Carver and Turoff [10], often forgotten.

Automation of crisis management systems essentially needs to be under the control of human actors [10], and with the possibility of being overruled. It can, however, be argued that applying higher degrees of automation to certain parts of crisis management systems could potentially streamline such machine networks and make them more efficient [17]. By automating appropriate tasks, such as automatic distribution of warnings or synthesizing of relevant information, the users can be given greater leeway to perform activities that require handling from human actors as they are based on human experience and knowledge. Such activities include collaborative tasks at all phases of crisis management, e.g. making complex decisions, implementing protective measures, and securing coordination across different organizations as a few examples.

### 5.3 Strengthening Social Ties of Dispersed Human Resources

Humans in the investigated network have medium strong relationship with each other. This is typical within crisis management, as the people working together to solve a crisis event come from different organizations and are often dispersed. The social relations between people in the network vary to some extent, depending on the network scope. Participants point out that internally in the organizations, relations are generally strong, while between organizations they are somewhat weaker. Tie strength also vary depending on the situation in which the network finds itself. During normal state (no on-going crisis), collaboration usually takes place between people with closer relations. However, during handling of a crisis, the network expands and collaboration between magnitudes of people with varying degrees of social ties occurs.

Although social ties are important in crisis management as in all work settings requiring collaboration, participants highlight that knowing the role and authority of others is of equal or more importance within this particular domain. It is assumed that a person within a certain work position will handle his or her responsibilities in a satisfying manner, independent of the strength of the social ties with the persons he or she collaborates with. There is, however, an ambition to strengthen the social ties between human actors in the network, as it is often easier to collaborate with people one knows.

Strong social ties foster successful collaboration, while lack of social ties may have negative implications on collaboration and the use of the CMT. This applies both within and across organizational boundaries. One end-user exemplified how social ties is connected to the commitment to use a common system.

> *"If you and I know each other, it is much harder for you to ignore me when I say that you have to use the CMT. If you do not know me, it is much easier for you not to care and not use the system. So it is like in all other contexts, that relationships fosters commitment, for better and worse."* (CMT end-user)

Establishing strong social relationship is a challenge that exists within the crisis management domain in general, and is not solely connected to the particular network

involving the CMT. The challenge is especially apparent during handling of crisis events that require the collaboration between several actors and organizations, where weak social ties can potentially hinder efficient collaboration as the essential knowledge of and trust in each other is missing.

A well-designed crisis management system has the potential to increase social ties and strengthen collaboration between human actors in the network by providing a common platform for collaboration, in addition to information about participating actors and organization, and being a mean for information sharing. Joint and regular training sessions between crisis management organizations was also mentioned by participants as a way of strengthening interpersonal knowledge and social ties. In such training sessions, a natural part of the training should be exercising the use of and collaboration through systems for crisis management. Thus, it is important not to forget that the system is a central part of the network. Forums where users of a system or tool can meet to discuss and learn from each other can also contribute useful arenas for strengthening ones' knowledge of and relationships to colleagues and collaborative partners.

### 5.4 Extending the Use of a Common Crisis Management System

The size and geographical reach in which the CMT is used is rather limited. Although the global network of people involved in public crisis management is relatively large, the particular network is limited as the use of the CMT within public crisis management organizations varies. The network currently extends over a restricted geographical area, with little variation in culture and jurisdictions. The CMT is mainly used within a few countries and continents. The ambition for the future is to extend the use and the user group of the CMT, and that the tool is being adopted and used worldwide.

The limited size and geographical reach of the network does not directly entail negative implications for the network. However, the varying degree in which end-users in public crisis management organizations utilize the CMT affects collaboration. Ideally, for the CMT to function as common platform, all relevant crisis management actors should be using the tool for information sharing and coordination.

Furthermore, the lack of use among some public crisis management organizations has implications on the network's motivation for using the tool, according to the participants. Users might not see the value of the tool when important collaboration partners are absent. One of the end-users exemplified this point through the following quote.

> "*There's no point that we send out information, unless it is read at the other end and responded to.*" (CMT end-user)

There exist a variety of systems for crisis management, and a challenge for collaboration is that different crisis management organizations often use different systems that do not support communication, sharing of information, and coordination across systems. To stay up-to-date on the situation and maintain a holistic operational picture, there is a clear need for collaboration to take place through joint collaborative systems that include information from the several sources participating in the management of an event. As many of the end-user participants stated, such system should hold the possibility for integration with other systems.

The CMT provider's foremost ambitions for extending the network size involves getting more of the public crisis management organizations to use the tool. To function as common platform that can support collaboration through joint coordination, communication, and sharing of information, all relevant crisis management actors and organizations should ideally use the same system. One of the interviewed end-user answered the following when asked how to increase the use of the CMT among public crisis management organizations.

> *"I think it simply has to be a greater degree of commitment or in other words it should be mandatory. And basically, that is not something positive. But yet, I don't think there is anything else that will work, really. Or have the higher authorities use the CMT for information sharing with the public sector organizations so that they [the public sector organizations] actually have to use the CMT to get the information."* (CMT end-user)

Encouraging the higher authorities to use the CMT in communication with public crisis management organizations is, as the above extract states, one possibility of increasing the use of the tool. Another solution is to establish formal requirements for use of the CMT in the public sector.

For technology to serve as intended during the management of crisis events, the users need to be familiar with how to utilize the system in an efficient manner. The technology should therefore also be useful for accomplishing tasks in the before and after stage of a crisis, and preferably be used on a daily basis. One of the CMT representatives expressed how regular use can have beneficial effects when a crisis occurs.

> *"From experience, we know that the more you use a system, the better you use it. So the focus is more and more on using it on a daily basis. We see that those who use the tool daily or at least regularly, they experience increased confidence in using the tool during the management of crisis situations."* (CMT representative)

To emphasis the importance of organizations participating in the use of a common system for crisis management is vital for efficient collaboration. Increased use can be accomplished through arenas where beneficial effects of use are highlighted, preferably exemplified by end-users who themselves have successfully utilized the system. Such arenas can also function as support groups where users can get help and learn from each other, as well as get ideas on how best to make use of the system and its functionalities.

## 6 Conclusion

In this paper, we have studied crisis management from a human-machine network perspective, and explored how characteristics of a crisis management networks may have implications on and affect collaboration. Arising from this, we have proposed three aspects that should be considered in future design and development of crisis management systems, with the purpose of supporting collaboration throughout the phases and activities that crisis management involve. First, we presented how higher degrees of automation can increase machine agency while at the same time giving human actors greater leeway to perform their tasks. Automation in crisis management systems should essentially be controlled by humans and have the possibility of being overruled. However, if automation is introduced to the correct tasks and elements, it can provide substantial

support for the human actors in the network, freeing them to concentrate on more demanding, cognitive tasks. Second, we highlighted the benefits of strengthening social ties or relationships between the dispersed human resources managing crisis events. Knowing the people one works with is recognized to support collaboration. There are several ways in which to strengthen social ties, e.g. through joint training sessions on a regular basis, as well as other arenas for socializing among colleagues. It should also be stressed that a well-design crisis management system functioning as common platform can potentially increase social ties and strengthen collaboration between human actors of a network. Third, we elaborated on how the use of a common crisis management system is crucial for efficient collaboration and effective crisis management. Specifically, it is important to extend the use among central public crisis management organizations by making visible and clearly communicate possible benefits and gains common use might lead to.

The method used, which involved interviews with both CMT representatives and end-users, made it possible to detect differences between the answers of the two groups. However, no noticeable discrepancies were found, and the participants seemed to have the same perception of the network, its implications, and possible solutions. Participants reported that the HUMANE approach provided a structured way to understand crisis management as a human machine network. Some even stated that the approach made them reflect upon elements and topics not frequently reflected on, such as social ties, which clearly have an impact on the collaboration within the network.

As all studies, this as well has its limitations. We acknowledge that the number of participants in the study could have been higher, especially concerning the end-user participants. Even though the interviews conducted provided highly valuable in-depth information, efforts should be made to include a larger sample of participants in similar future studies. Moreover, the sample in this study did not include crisis management personnel that work out in the field during crisis incidents. A suggestion for future studies is therefor to investigate the human-machine network within these groups and identify design challenges and opportunities to better support collaboration. In addition, the development of the profiles is, to some degree, a subjective process. Even though discrepancies were resolved though communication and the profiling were validated by presenting it to the CMT representatives, we recognize that the profiling can, potentially be vulnerable to researcher bias. Validation of the profile is therefore advised.

Designing efficient crisis management systems is certainly challenging due to the complexity involved in crisis management. In addition to meeting the requirements of the different actors involved, a crisis management system should preferably be of a flexible character that gives room for improvisation. It should be useful in all phases of crisis management, and adaptable to support the management of different types of events.

This study has aimed to provide designers and developers of crisis management systems with an understanding of crisis management as a complex human-machine network where different dimensions of the network should be considered. When developing technology, it is of high importance to take into account the purpose and role it is supposed to serve, and the impacts new technology might pose [10]. Technology for crisis management, as well as for many other domains, should be designed to support

the human actors, while at the same time be considered as an important actor and team member itself.

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